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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-08)

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J. N. Simpson and C. R. Tinsley

ARO, Inc.

January 1968

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LARGE ROCKET FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Aviation, Inc., Rocketdyne Division, manufacturer of the J-2 rocket engine, and Douglas Aircraft Company, manufacturer of the S-IVB stage. The testing reported herein was conducted on September 12, 1967, in the Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on October 16, 1967.

This technical report has been reviewed and is approved.

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Director of Test

ABSTRACT

Four firings of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. The firings were accomplished during test period J4-1801-08 at pressure altitudes ranging from 92,500 to 107,000 ft at engine start. The objectives of the test were to evaluate S-IVB/S-V start condition effects on (1) engine start transients, (2) gas generator outlet temperature, (3) augmented spark igniter operation, and (4) fuel pump high level stall margin for J-2 engine S/N J-2052. The accumulated firing duration was 70.32 sec. Satisfactory engine operation was obtained.

CONTENTS

APPENDIXES

NOMENCLATURE

A	Area, $in.^2$
ASI	Augmented spark igniter
ES	Engine start, designated as the time at which helium control and ignition phase solenoids are energized
GG	Gas generator
MOV	Main oxidizer valve
STDV	Start tank discharge valve
t_0	Time at which opening signal is applied to the start tank discharge valve solenoid
VSC	Vibration safety counts, defined as engine vibration in excess of 150 g rms in a 960- to 6000-Hz frequency range.

SUBSCRIPTS

f	force
m	mass
t	throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 engine (S/N J-2052) using an S-IVB battleship stage has been in progress since July 1966 at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The four firings reported herein were conducted during test period J4-1801-08 on September 12, 1967, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF) to investigate S-IVB/S-V start condition effects on (1) engine start transients, (2) gas generator outlet temperature, (3) augmented spark igniter operation, and (4) fuel pump high level stall margin. These firings were conducted at pressure altitudes ranging from 92,500 to 107,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start. The results of the previous test period are reported in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Aviation, Inc. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 225,000 lb_f at an oxidizer-to-fuel mixture ratio of 5.5. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively. The thrust chamber heater blankets were in place during this test period, although they were not utilized.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5 through 7, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length (L^*) of 24.6 in., a 170.4-in.^{2} throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.
2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.^{2}, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.
3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.
4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage, axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 35,517 ft (1225 psia) of liquid hydrogen at a flow rate of 8414 gpm for a rotor speed of 26,702 rpm.
5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2117 ft (1081 psia) of liquid oxygen at a flow rate of 2907 gpm for a rotor speed of 8572 rpm.
6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy

gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine. crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.^{3} sphere for hydrogen with a 1000-in.^{3} sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.

15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 Oxidizer Pump Primary Seal Drain Tubes

Fourteen oxidizer pump primary seal drain tubes were attached to the thrust chamber for this test (Fig. 8) to determine a drain configuration for a proposed modification to the S-II and S-IVB stage engines on vehicle AS-501. This was a continuation of the drain tube testing initiated on test J4-1801-07 (Ref. 2). Eleven of these tubes extended into the engine exhaust jet during engine operation; two of these 11 were supplied gaseous oxygen from a facility source to simulate the limits of the expected range of oxidizer pump primary seal leakage. Three tubes, including the actual oxidizer pump seal drain, did not extend into the engine exhaust jet but were canted outboard near the thrust chamber exit. A description of each tube and applicable instrumentation is detailed in Table V.

2.1.3 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46, 000 lb of liquid hydrogen and 199, 000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen for fuel tank pressurization during S-IVB flight was routed to the facility venting system.

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lb_f-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

A system was provided for temperature conditioning of engine components as required. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber and crossover duct. Helium was routed internally through the crossover duct and tubular-walled thrust chamber.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Engine side loads were measured with dual-bridge, strain-gage-type load cells which were laboratory calibrated before installation. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers, load cells, and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second and recording on magnetic tape; (2) single-input, continuous-recording FM systems recording on magnetic tape; (3) photographically recording galvanometer oscillographs; (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts; and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

SECTION III
PROCEDURE

Pre-operational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components which required temperature conditioning were the thrust chamber and crossover duct. Table VI presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Four firings of the J-2 rocket engine (S/N J-2052) were conducted on September 12, 1967, during test period J4-1801-08 in support of S-IVB/S-V test objectives. These firings were obtained at pressure altitudes ranging from 92,500 to 107,000 ft at engine start. The total firing duration on this test was 70.32 sec. The accumulated total firing duration on this engine at AEDC at the end of this test was 1402.3 sec, which resulted from 89 engine firings.

Thermal conditioning of the thrust chamber, the turbines, and the crossover duct was accomplished to simulate the predicted flight environment for J-2 engine (1) first burn and (2) restart, 80 min after first burn cutoff. A propellant utilization valve excursion to the full-closed position was conducted on the 30-sec firings at about t_0 + 14 sec. The oxidizer pump primary seal drain experiments, in support of a proposed modification to AS-501, S-II and S-IVB stage engines, were conducted on the initial firing. Flight prevalve sequencing (auxiliary start sequence) for J-2 engine first burn was utilized on firing 08C. Table VII presents conditioning targets for engine components and the measured test conditions at engine start.

Specific test objectives and a brief summary of results obtained for each firing are presented in the following.

Firing	Test Objectives	Results
08A	Evaluate the effects of ambient temperature thrust chamber on fuel pump high level stall. Evaluate chamber pressure buildup time with the propellant utilization	Fuel pump high level stall margin was about 500 gpm. Buildup time to a chamber pressure of 550 psia was 2.79 sec, the maximum experienced for engine restart. The seal drain burnout tubes

Firing	Test Objectives	Results
08A	valve in the full open position at engine start. Evaluate burn characteristics and pressure recovery of oxidizer pump primary seal drain tubes for proposed AS-501, S-II and S-IVB stage engine modification.	equipped with the blowout port exhibited the least pressure recovery.
08B	Evaluate start tank pressure and temperature effects on gas generator and turbine performance for an 80-min restart.	Gas generator outlet temperature peaked at 2090°F with no second peak. During start tank discharge, peak oxidizer turbine speed was 3390 rpm; fuel turbine speed at the same time was 12, 300 rpm.
08C	Evaluate augmented spark igniter ignition characteristics with a low starting mixture ratio. Compare ignition characteristics to those of firing J4-1801-06C which utilized a nonstandard immersion depth of the augmented spark igniter ignition detect probe.	Augmented spark igniter ignition was satisfactory. Ignition detect delay was 454 msec compared to 3440 msec on firing 06C. Post-test inspection revealed no excessive augmented spark igniter erosion.
08D	Evaluate start tank pressure effects on gas generator and turbine performance for an 80-min restart.	Gas generator outlet temperature peaked at 2150°F. During start tank discharge, peak oxidizer turbine speed was 3680 rpm; fuel turbine speed at the same time was 13, 200 rpm.

The presentation of the test results in the following sections will consist of a discussion of each engine firing with pertinent comparisons. The data presented will be that recorded on the digital data acquisition system, except as noted.

4.2 TEST RESULTS

4.2.1 Firing J4-1801-08A

Firing 08A was 30 sec in duration with a propellant utilization valve excursion from full open to full closed at t_0 + 13.4 sec. The turbines and crossover duct were thermally conditioned before engine start as shown in Fig. 10. Fuel lead duration was 8 sec.

Engine start and shutdown transients of primary engine parameters are shown in Fig. 11. Second-stage movement of the main oxidizer valve began at t_0 + 0.985 sec. Main chamber ignition occurred at t_0 + 1.060 sec with only 2 msec of engine vibration (VSC). The gas generator outlet temperature peaked at 1050°F. Main chamber pressure buildup to 550 psia occurred at t_0 + 2.791 sec (the longest buildup time to date at AEDC). Engine ambient and combustion chamber pressures for the duration of the firing are shown in Fig. 12. Pressure altitude at engine start was 92,500 ft.

Start transient fuel pump head/flow data are compared with the stall inception curve provided by the engine manufacturer in Fig. 13. The minimum stall margin in the region above 17,500 rpm is about 500 gpm.

A summary of the engine valve operating times for both start and shutdown is presented in Table VIII. Valve operations were normal.

The oxidizer pump primary seal drain experiments were conducted to assist the engine manufacturer in developing a drain tube which, at burnout of the capped end extending into the engine exhaust jet, would allow unrestricted seal leakage flow and exhibit satisfactory burn characteristics. This was in support of a proposed modification to the oxidizer pump primary seal drain on the S-II and S-IVB stage engines, vehicle AS-501. The tubes of primary interest were (1) tube numbers 5 and 6 which were supplied gaseous oxygen to simulate maximum and minimum leakage, respectively, expected from the pump seal; (2) the actual seal drain, tube number 1, which was instrumented to determine performance of the modified seal drain configuration (Table III); and (3) tube numbers 2, 3, 4, 7, 8, 9, 10, 11, and 12, which were instrumented to determine engine exhaust pressure recovery and burn characteristic information. Table V contains a description of each tube and a detailed listing of applicable instrumentation.

End burnout of tube number 5 occurred at t_0 + 4.1 sec, and subsequently, a gaseous oxygen flow rate of approximately 100 scfm was established. End burnout of tube number 6 occurred at t_0 + 4.4 sec, and subsequently, a gaseous oxygen flow rate of approximately 145 scim was established. The pressure data obtained from these tubes are presented in Fig. 14a.

Pressure data on the performance of the actual seal drain are presented in Fig. 14b for (1) upstream of the oxidizer pump primary seal (bearing coolant pressure), (2) downstream of the primary seal (seal cavity pressure), and (3) in the drain tube near the oxidizer pump. Typical pressure data from the remainder of the tubes of interest are presented in Fig. 14c. The data are from the tube of each type (Table V) which exhibited the maximum pressure recovery. Tube number 3, equipped with a soft-soldered blowout port, exhibited the least pressure recovery (about 1 psia during engine steady-state operation) of the three tubes compared.

Engine steady-state performance data are presented in Table IX. The data were computed using the Rocketdyne PAST 640 modification zero performance program. Engine test measurements required by the program and the program equations are presented in Appendix IV.

Comparison of performance data from firing 07C (Ref. 2) with firing 08A indicates fuel turbine efficiency decreased 5.6 percent (from 59.2 to 55.9 percent). Turbine erosion caused by firing 07D (observed on post-test 07 fuel turbine inspection) degraded turbine performance. This degradation must preclude the general comparison of start transient performance on this test to other tests without application of some normalizing technique.

4.2.2 Firing J4-1801-08B

Firing 08B was conducted 18 min after engine cutoff on firing 08A to provide turbine and crossover duct temperatures (Fig. 15) equivalent to predicted orbital engine restart 80 min after first burn cutoff. This firing was 5 sec in duration preceded by a fuel lead of 8 sec. The propellant utilization valve was fully open throughout the firing. Start tank energy on this firing was the lowest utilized to date at AEDC to start the J-2 engine.

Engine start and shutdown transients of primary engine parameters are shown in Fig. 16. Second-stage movement of the main oxidizer valve began at t_0 + 1.100 sec. Main chamber ignition occurred at t_0 + 1.007 sec without engine vibration (VSC). The gas generator outlet temperature peaked at 2090°F. Engine ambient and combustion chamber pressures for the duration of this firing are shown in Fig. 17. Pressure altitude at engine start was 101,000 ft.

Start transient fuel pump head/flow data are compared with the stall inception curve provided by the engine manufacturer in Fig. 18. There were no stall tendencies.

A summary of engine valve operating times for both start and shutdown is presented in Table VIII. Valve operations were normal.

4.2.3 Firing J4-1801-08C

Firing 08C was 30 sec in duration with a propellant utilization valve excursion from null to full closed at t_0 + 13.8 sec. The turbines and crossover duct, as well as the thrust chamber, were thermally conditioned before engine start, as shown in Fig. 19. Fuel lead duration was 3 sec. Flight prevalve sequencing for J-2 engine first burn (auxiliary start sequence) was utilized on this firing.

Engine start and shutdown transients of primary engine parameters are shown in Fig. 20. Second-stage movement of the main oxidizer valve began at t_0 + 1.000 sec. Main chamber ignition occurred at t_0 + 1.027 sec with 34 msec of engine vibration (VSC). Engine ambient and combustion chamber pressures for the duration of the firing are shown in Fig. 21. Pressure altitude at engine start was 105,000 ft.

Start transient fuel pump head/flow data are compared with the stall inception curve provided by the engine manufacturer in Fig. 22. There were no stall tendencies.

A summary of engine valve operating times for both start and shutdown is presented in Table VIII. Although all valve operations were normal, the augmented spark igniter ignition detect signal de-energized for 477 msec at t_0 - 0.627 sec.

However, augmented spark igniter operation was satisfactory as evidenced by:

1. Normal ignition detect delay (454 msec),
2. Typical augmented spark igniter fuel injection and combustion chamber pressure transients, Fig. 20i, and
3. Absence of augmented spark igniter chamber erosion at post-test inspection.

Engine steady-state performance data are presented in Table IX. The data were computed using the Rocketdyne PAST 640 modification zero performance program. Engine test measurements required by the program and the program equations are presented in Appendix IV.

Fuel turbine efficiency decreased 5.2 percent (from 59.2 to 56.4 percent) as compared to firing 07C. As discussed in Section 4.2.1, turbine degradation evidently occurred on firing J4-1801-07D.

4.2.4 Firing J4-1801-08D

Firing 08D was conducted 20 min after engine cutoff on firing 08C to provide turbine and crossover duct temperatures (Fig. 23) equivalent to predicted orbital engine restart 80 min after first burn cutoff. This firing was obtained at the same start conditions as on firing 08B, except for a 200 psi higher start tank pressure on firing 08D. The firing was 5 sec in duration preceded by a fuel lead of 8 sec. The propellant utilization valve was fully open throughout the firing.

Engine start and shutdown transients of primary engine parameters are shown in Fig. 24. Second-stage movement of the main oxidizer valve began at t_0 + 0.974 sec without engine vibration (VSC). The gas generator outlet temperature peaked at 2160°F. Therefore, compared to firing 08B, the 200-psi increase in start tank pressure yielded a 70°F increase in gas generator peak outlet temperature. Engine ambient and combustion chamber pressures for the duration of the firing are shown in Fig. 25. Pressure altitude at engine start was 106,500 ft.

Start transient fuel pump head/flow data are compared with the stall inception curve provided by the engine manufacturer in Fig. 26. There were no stall tendencies.

A summary of engine valve operating times for both start and shutdown is presented in Table VIII. Valve operations were normal.

4.3 POST-TEST INSPECTION

Post-test inspection showed the engine to be in satisfactory condition. Post-test photographs of the oxidizer pump primary seal drain tubes are presented in Fig. 27.

SECTION V
SUMMARY OF RESULTS

The results of these four firings of the J-2 engine (S/N J-2052) conducted on September 12, 1967, in Test Cell J-4 are summarized as follows:

1. The slowest chamber pressure buildup time, 2.79 sec, to date at AEDC was obtained on a restart simulation firing (08A). The fuel pump high level stall margin was 500 gpm.
2. A fuel turbine efficiency decrease of approximately 5 percent was determined, from performance data comparisons of firings 07C, 08A, and 08C, to have occurred on firing 07D.
3. An engine restart firing (08B) after a simulated 80-min orbital coast was satisfactorily obtained with the lowest start tank energy utilized to date at AEDC.
4. Augmented spark igniter ignition detect delay was satisfactory on a first burn simulation firing (08C), a repeat of a previous firing (06C) which yielded excessive delay.
5. Gas generator outlet peak temperature was increased about 70°F by the 200-psi increase in start tank pressure on comparable engine restarts (firings 08D and 08B) after simulated 80-min orbital coast periods.
6. Oxidizer pump primary seal drain tube experiments were conducted for a proposed modification to S-II and S-IVB stage engines on vehicle AS-501. The burnout tubes with soft-soldered blowout ports exhibited the least pressure recovery.

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APPENDIXES

I. ILLUSTRATIONS

II. TABLES

III. INSTRUMENTATION

IV. METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

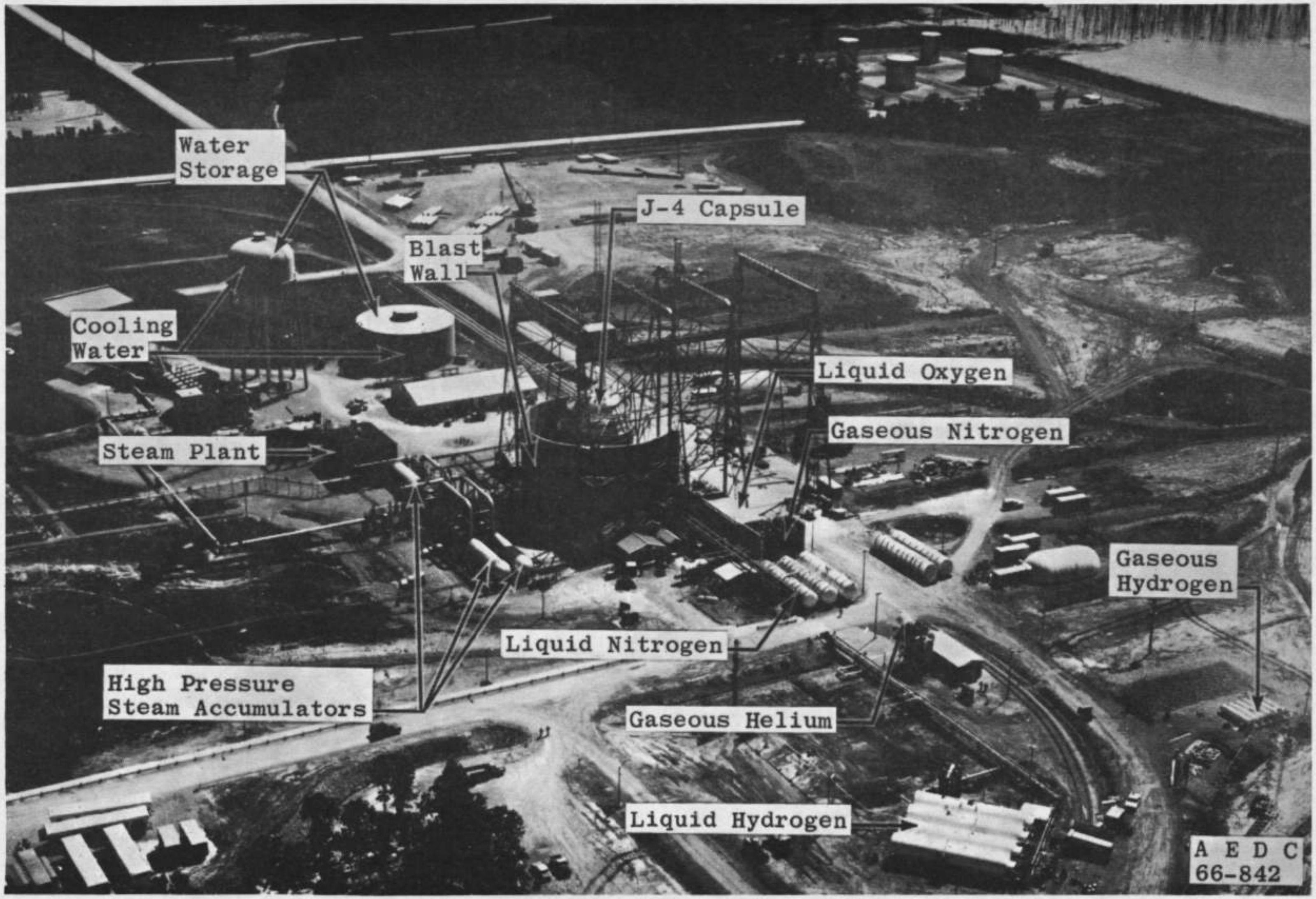


Fig. 1 Test Cell J-4 Complex

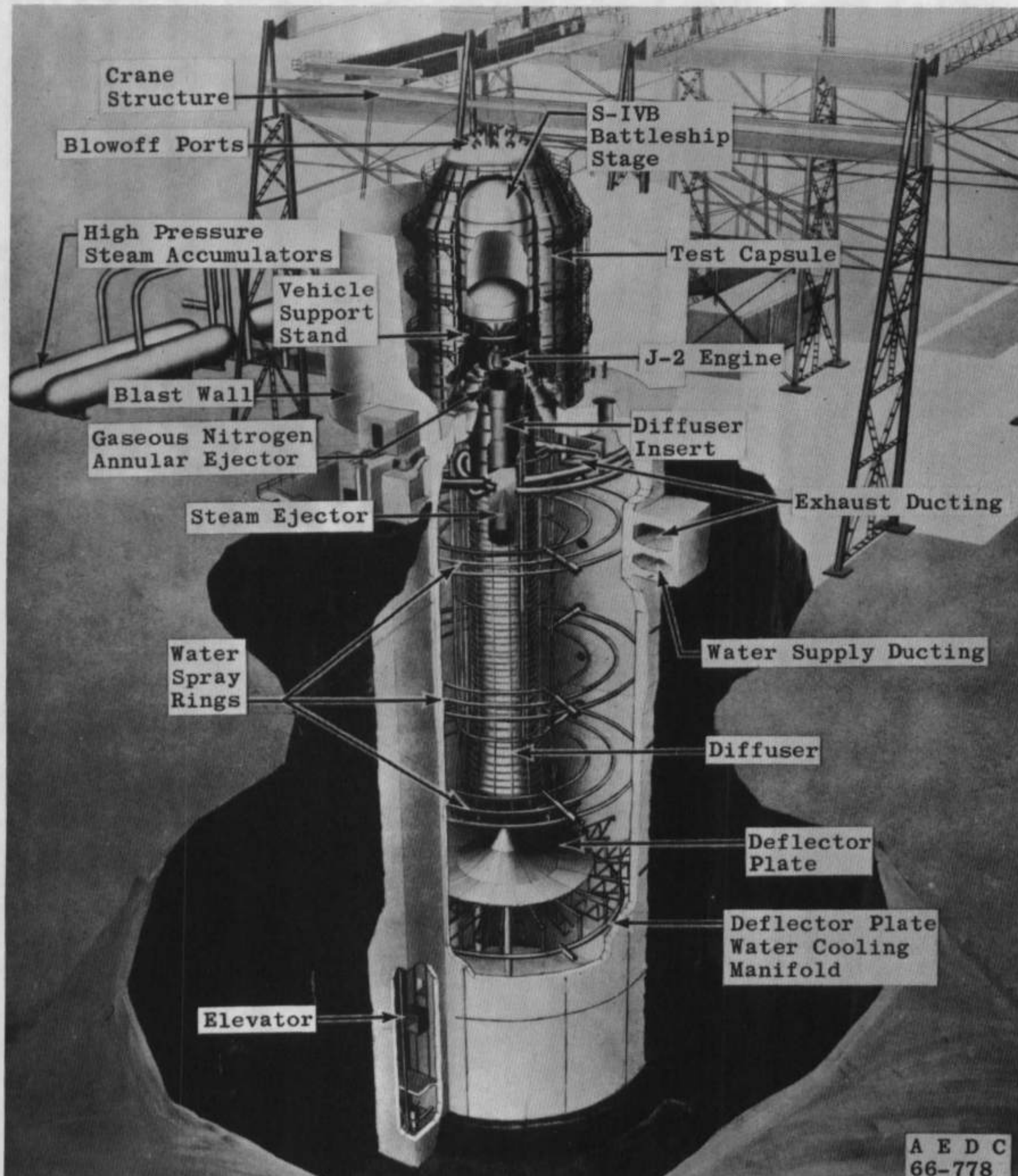


Fig. 2 Test Cell J-4, Artist's Conception

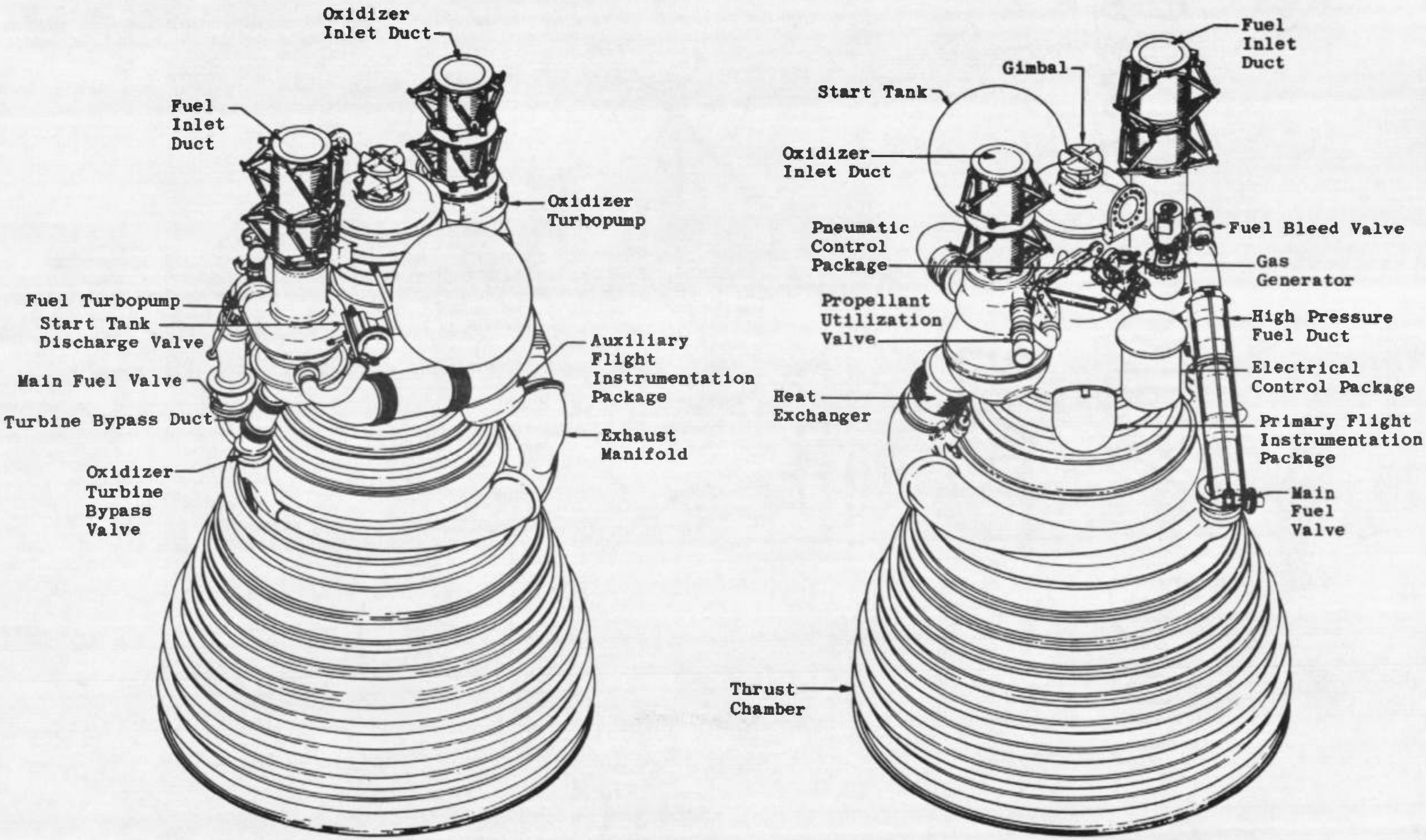


Fig. 3 Engine Details

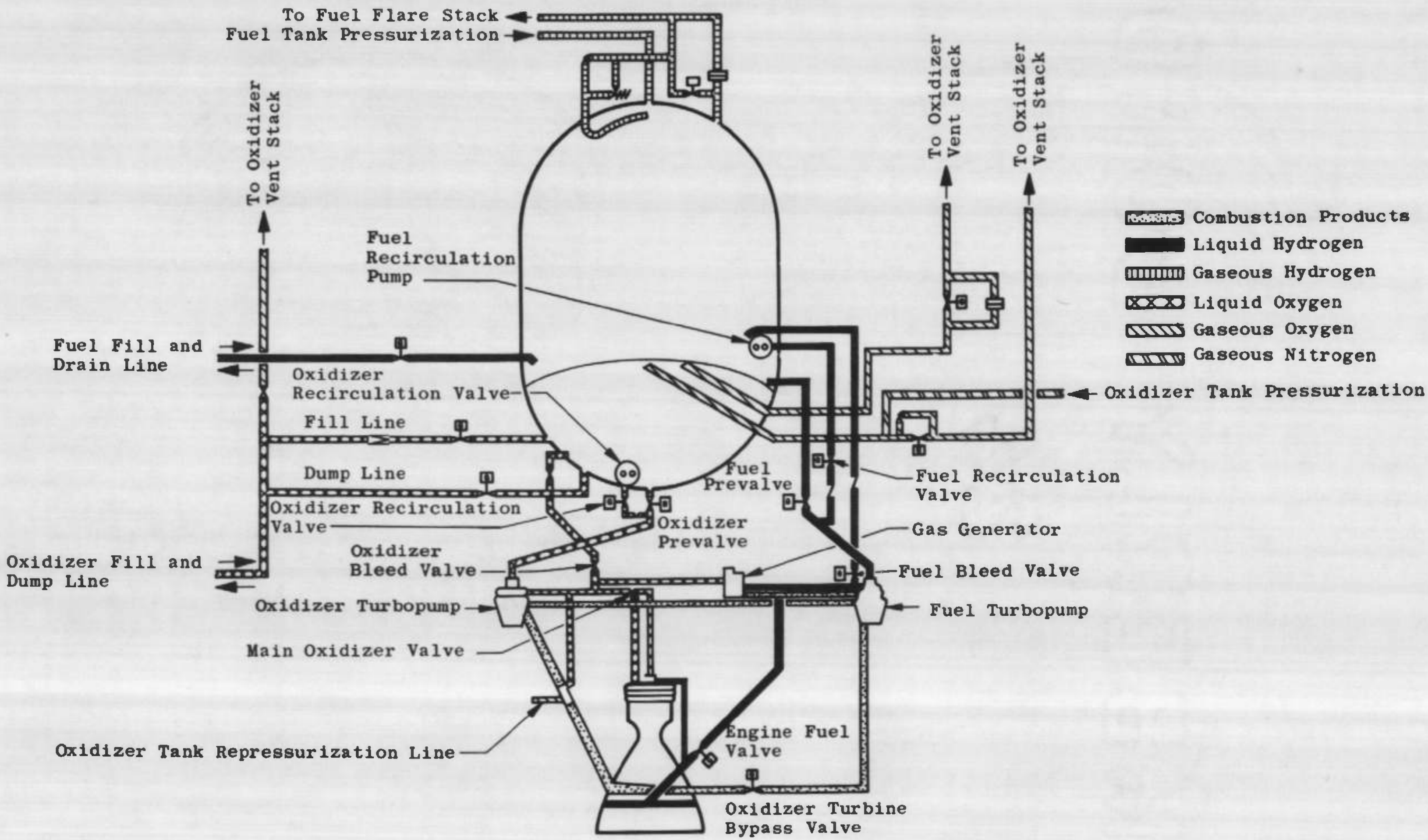


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

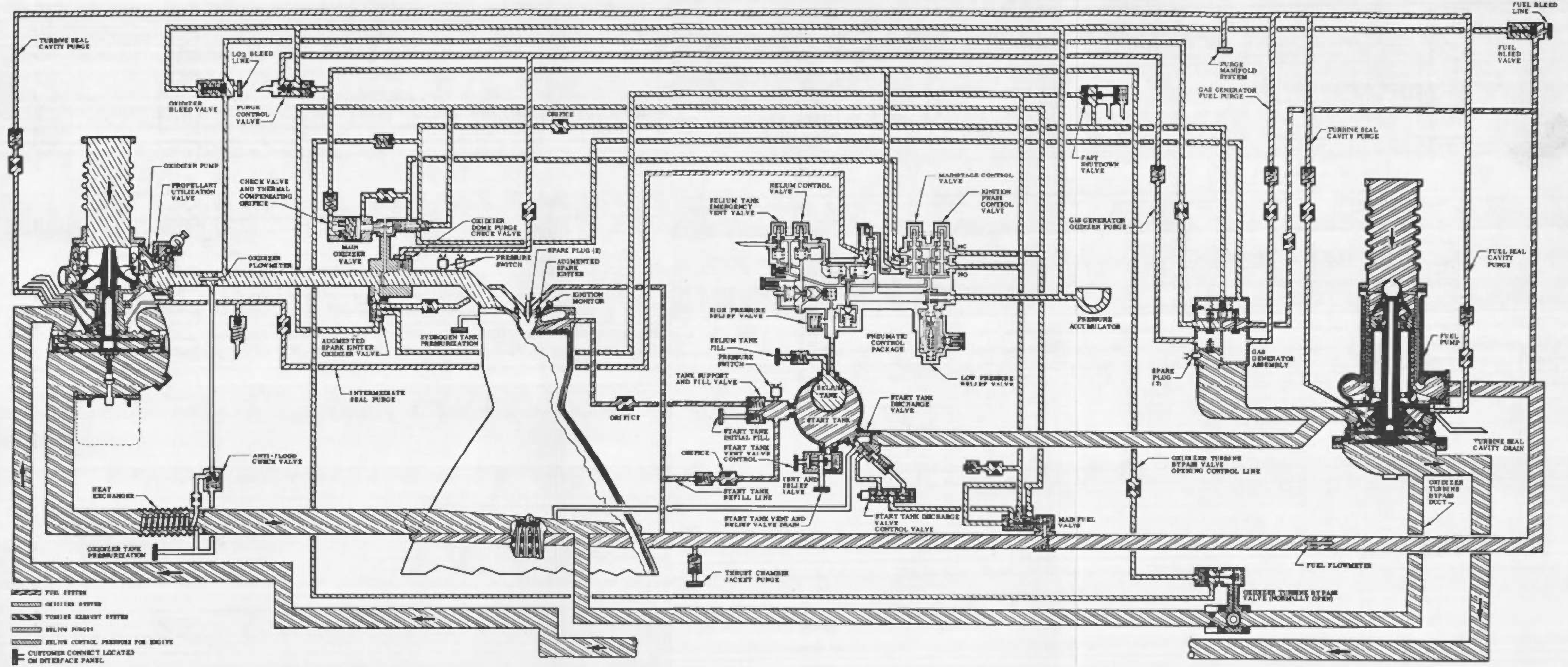


Fig. 5 Engine Schematic

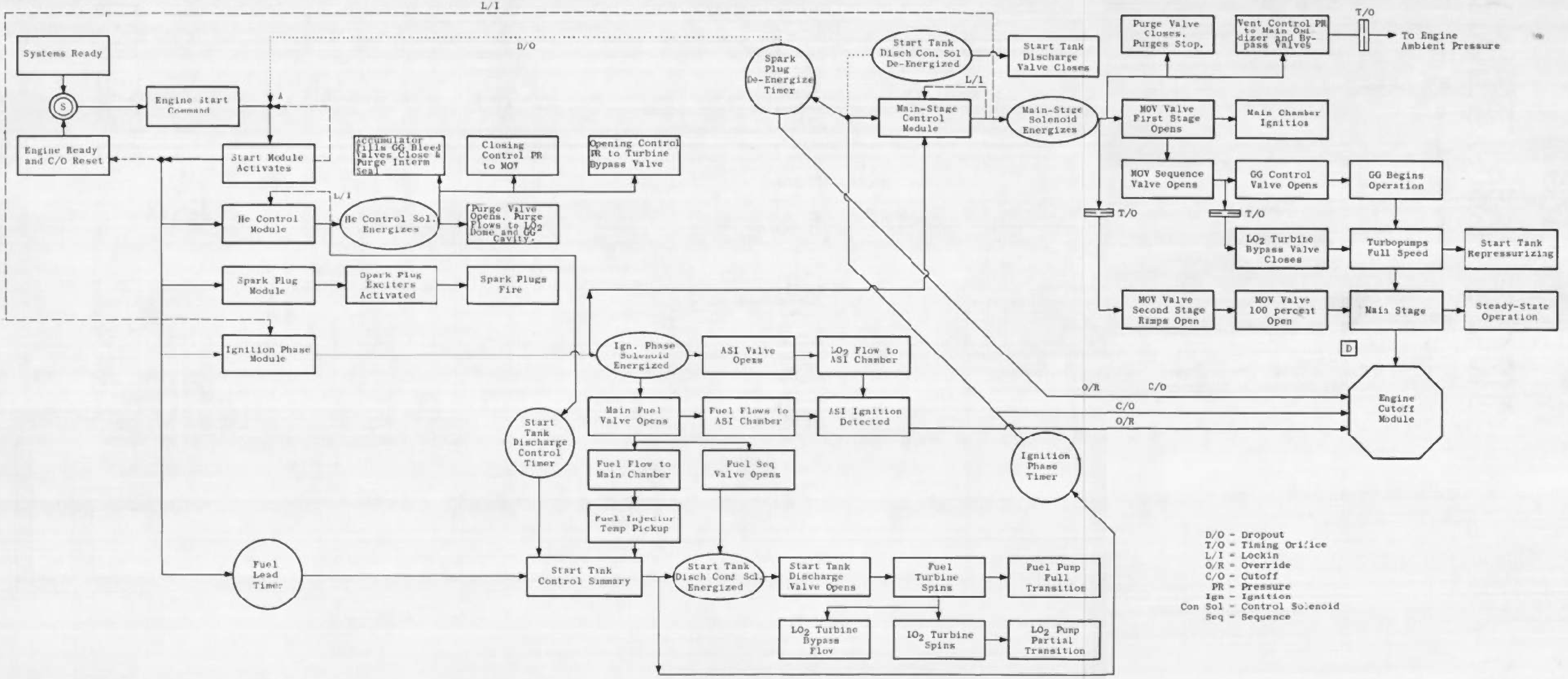
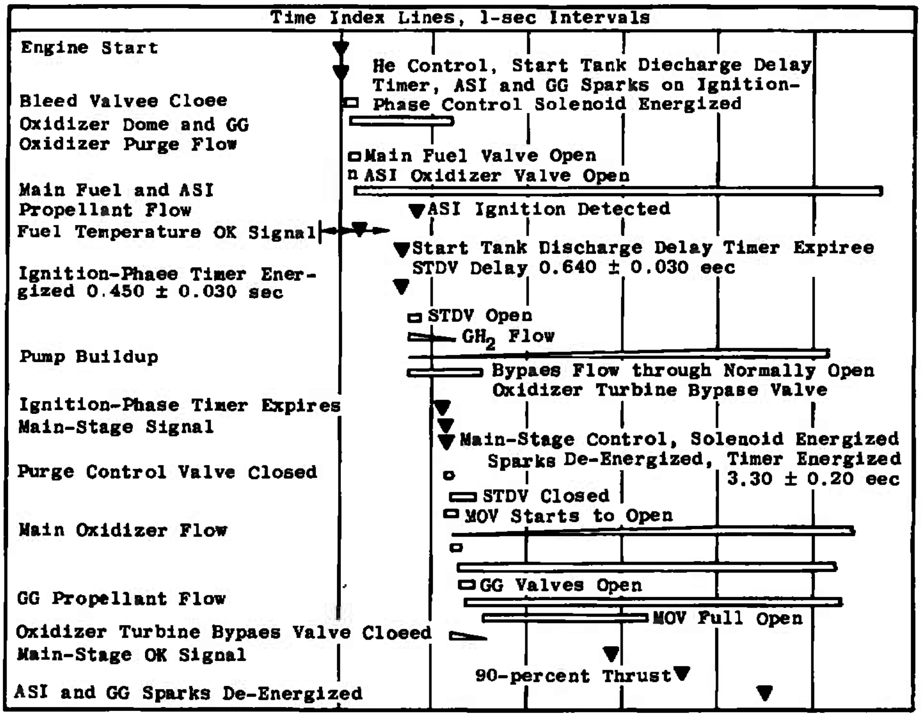
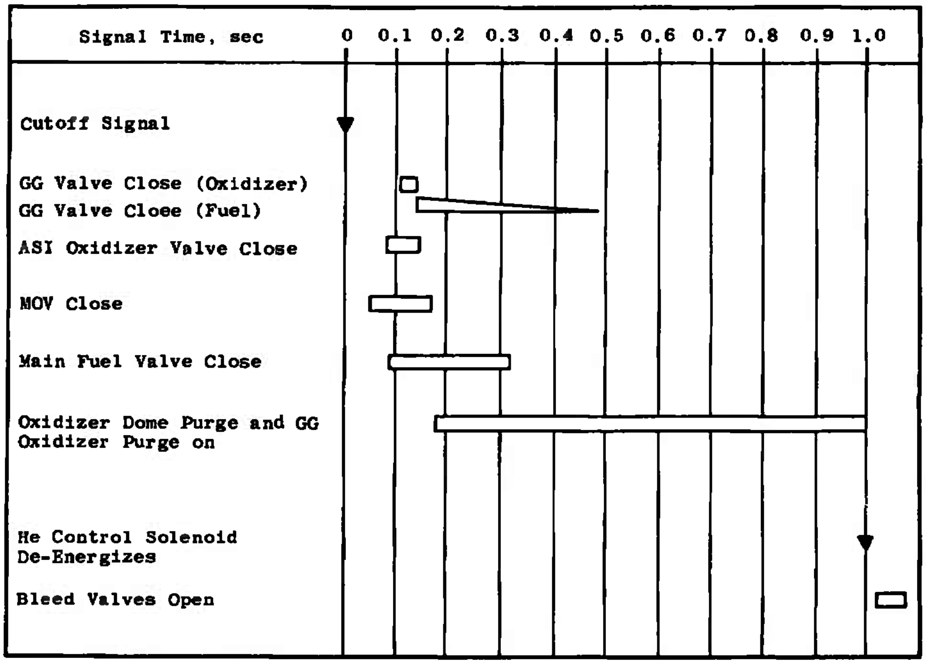


Fig. 6 Engine Start Logic Schematic

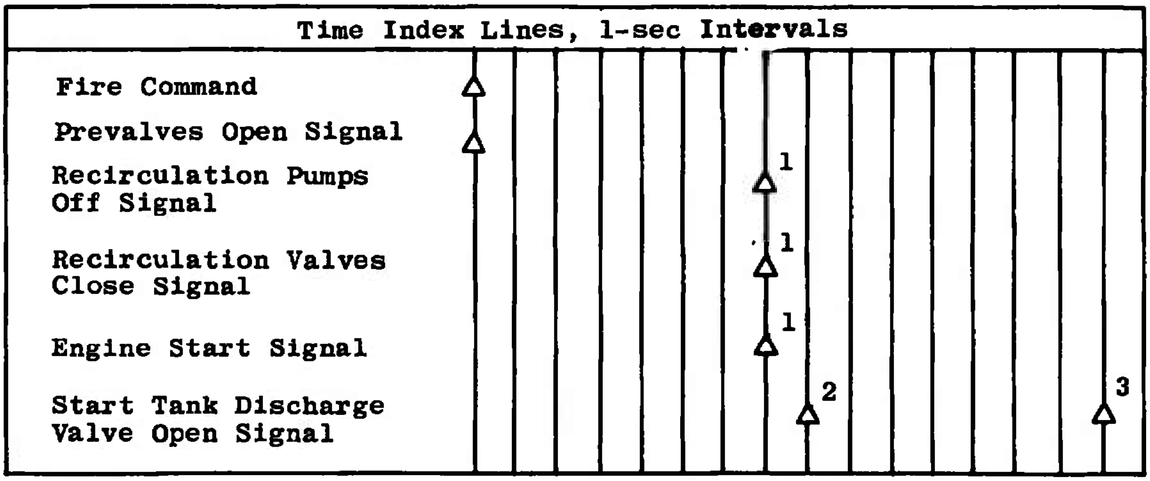


a. Start Sequence



b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence

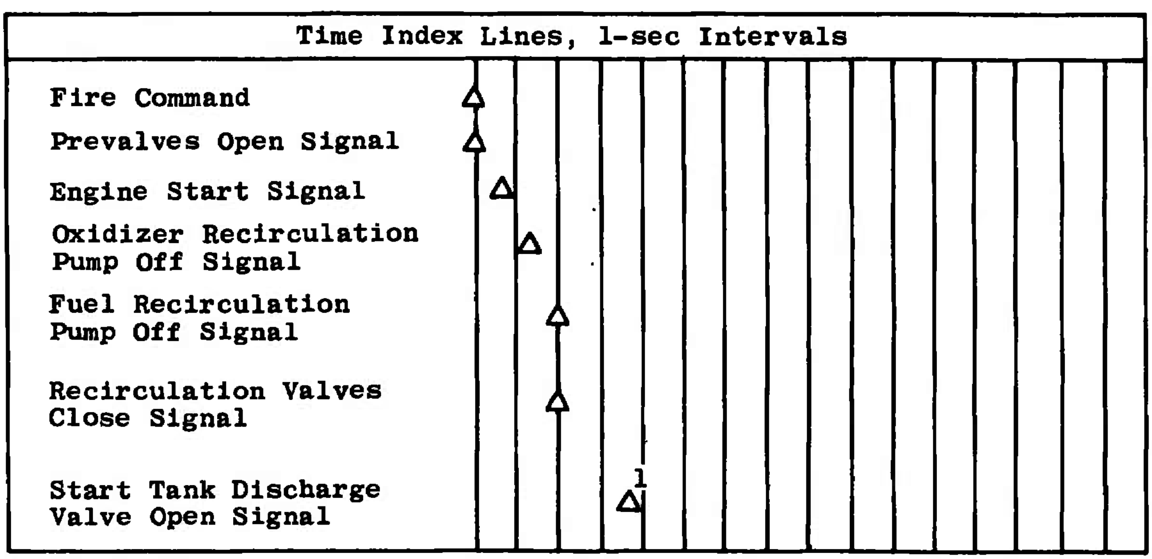


[1]Nominal Occurrence Time (Function of Prevalves Opening Time)

[2]One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)

[3]Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

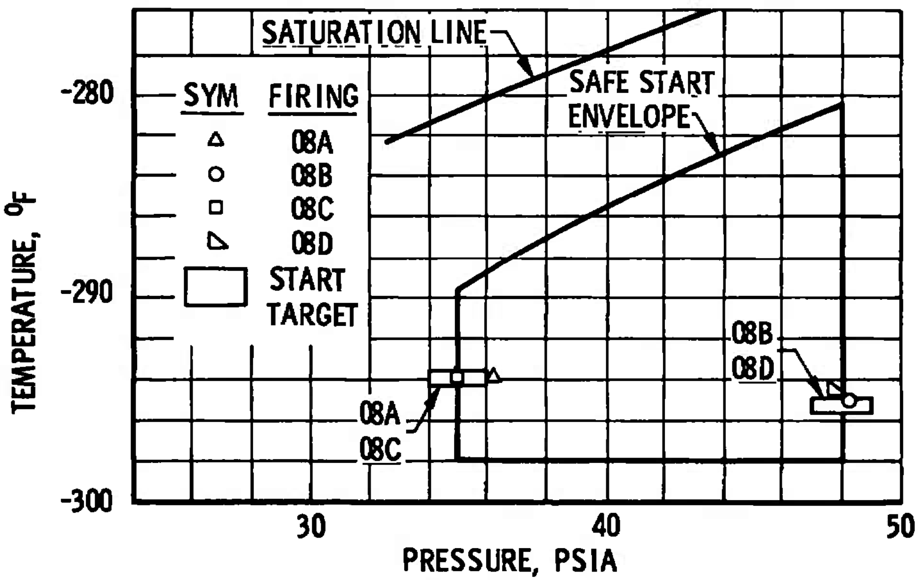
c. "Normal" Start Sequence



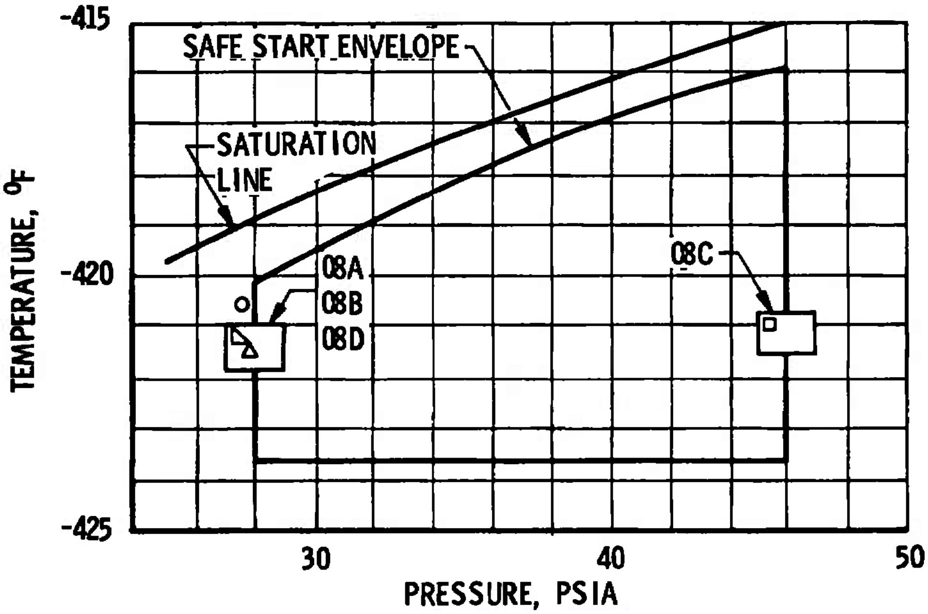
[1]Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. "Auxiliary" Start Sequence

Fig. 7 Concluded

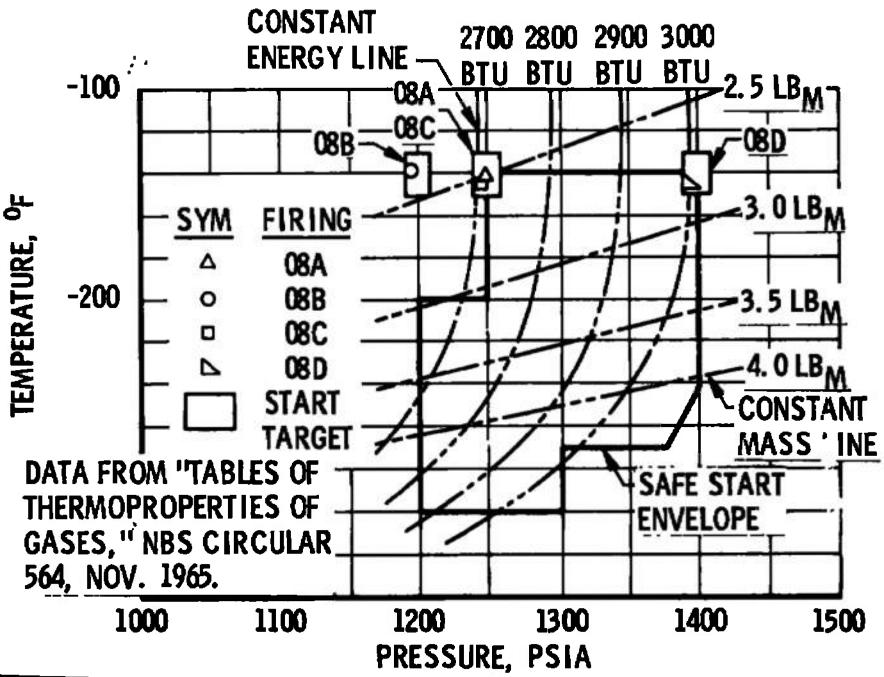


a. Oxidizer Pump Inlet

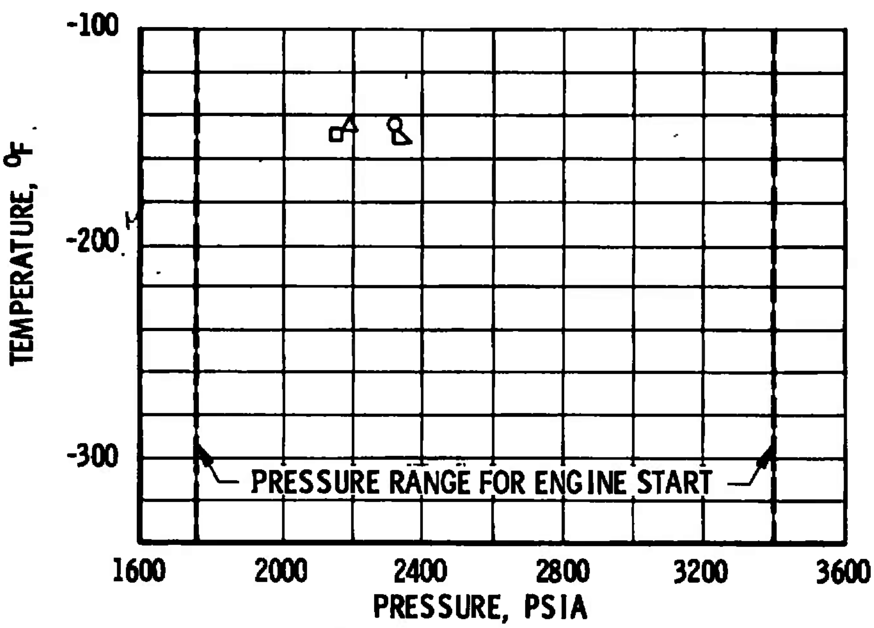


b. Fuel Pump Inlet

Fig. 8 Engine Start Conditions for Pump Inlets, Start Tank, and Helium Tank

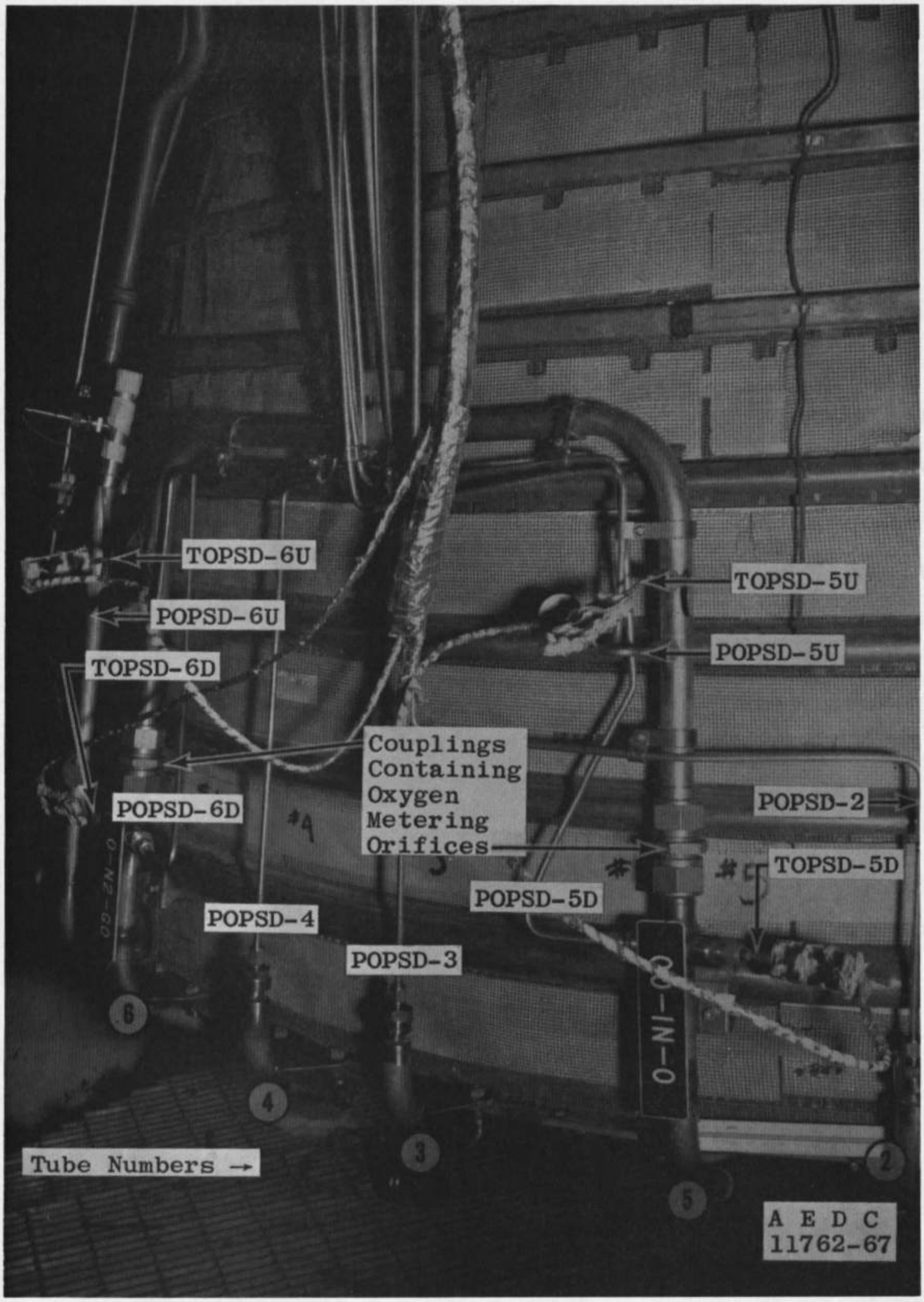


c. Start Tank



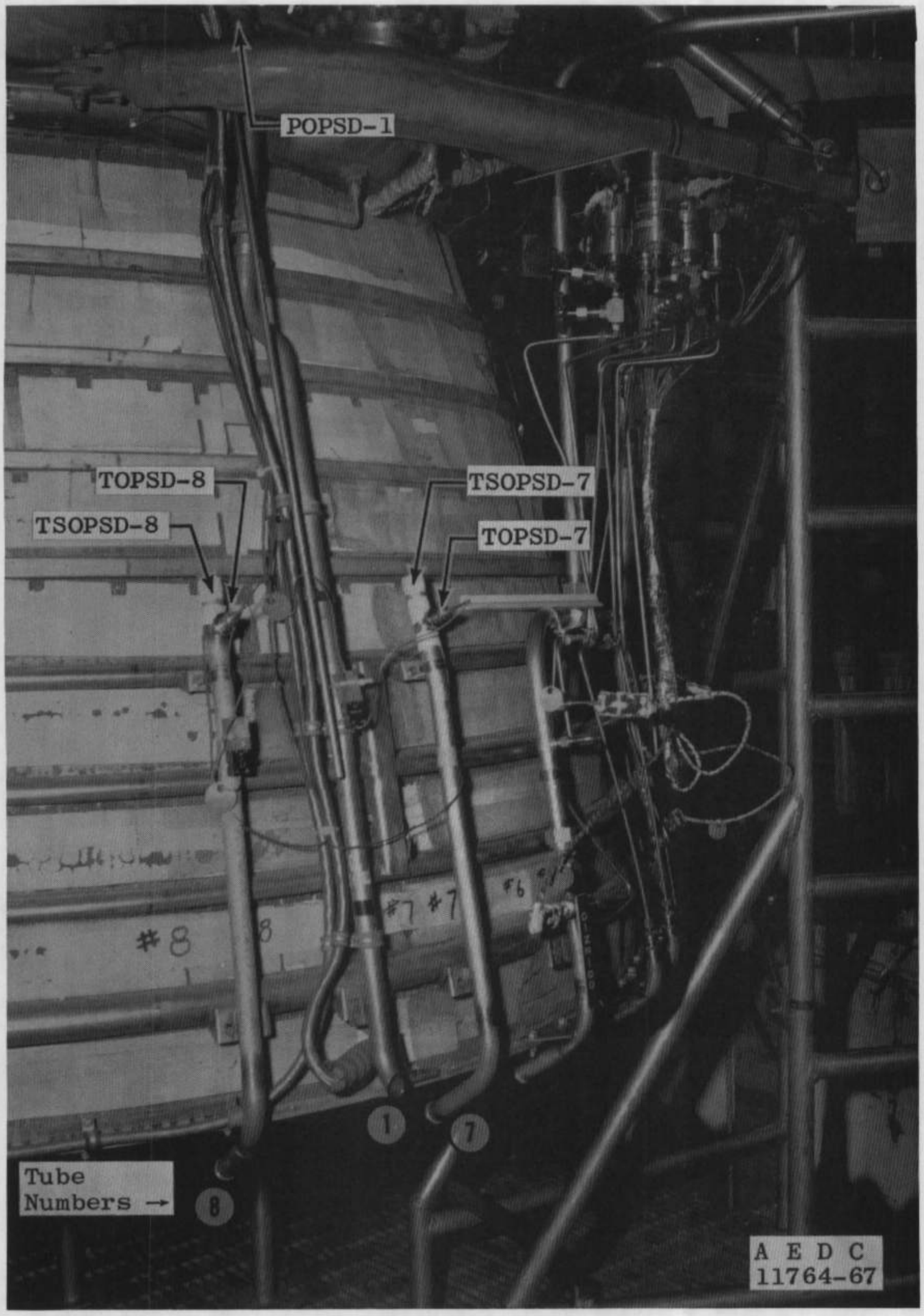
d. Helium Tank

Fig. 8 Concluded



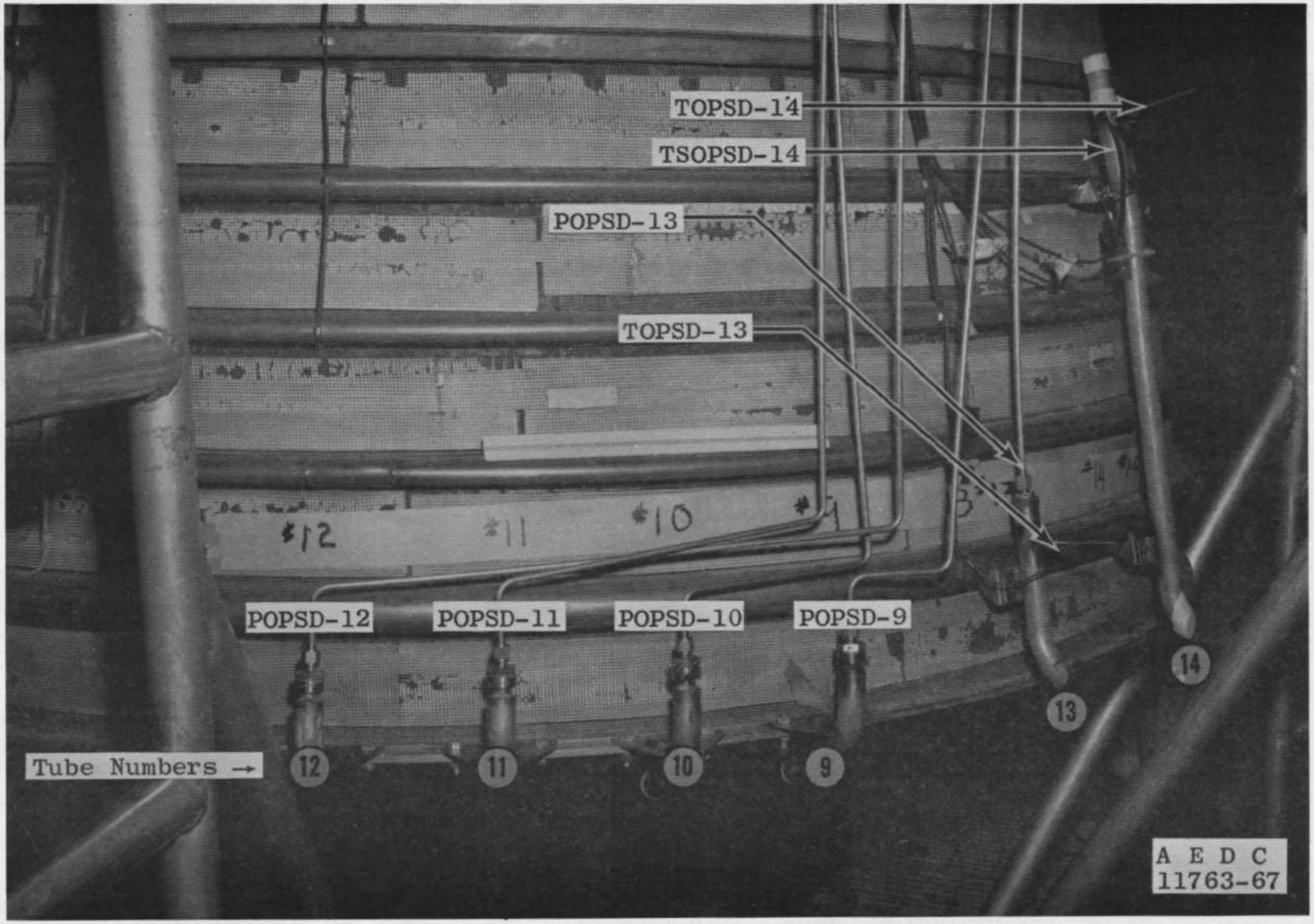
a. Tubes 2 through 6

Fig. 9 Oxidizer Pump Primary Seal Drain Tubes



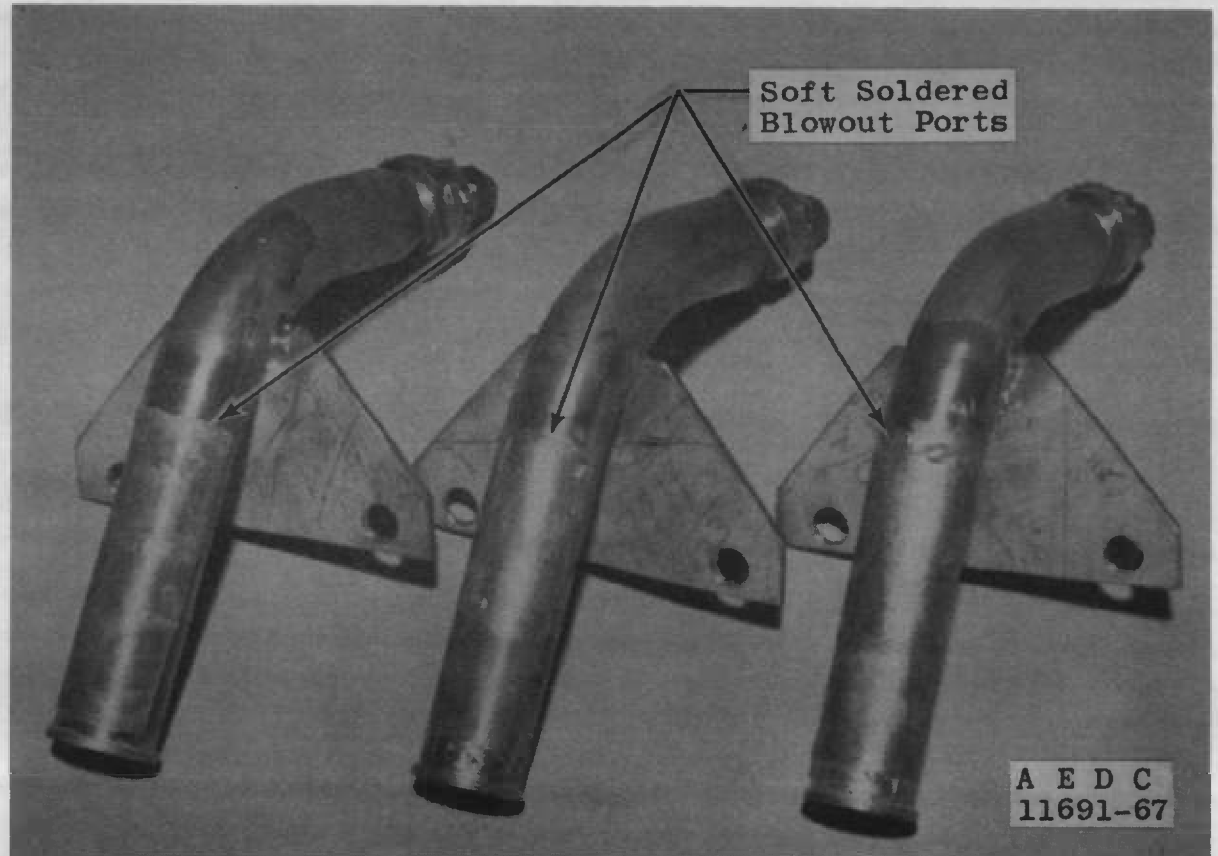
b. Tubes 1, 7, and 8

Fig. 9 Continued



c. Tubes 9 through 14

Fig. 9 Continued

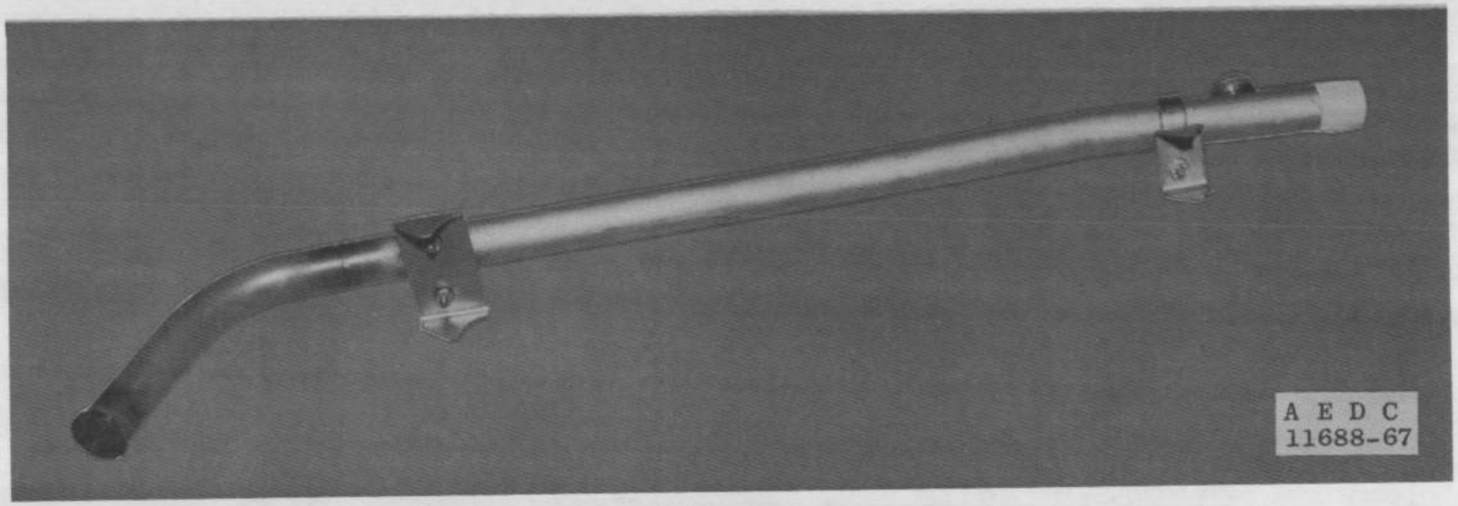


d. Left to Right, Tubes 2, 3, and 4

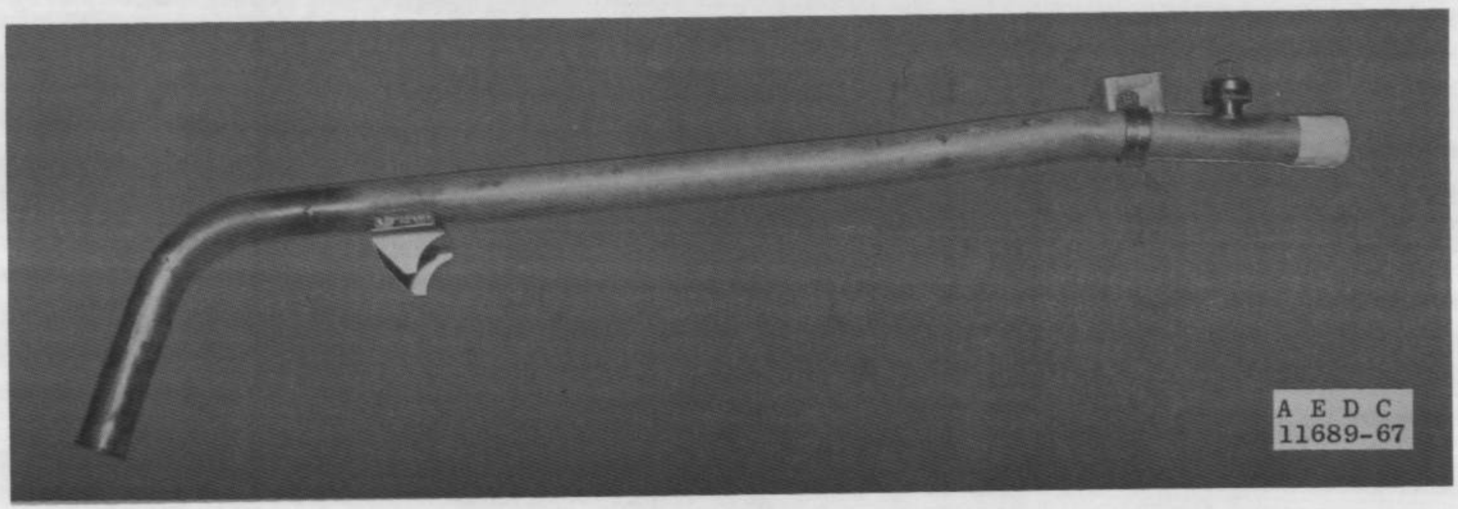
Fig. 9 Continued

e. Left to Right, Tubes 5 and 6

Fig. 9 Continued

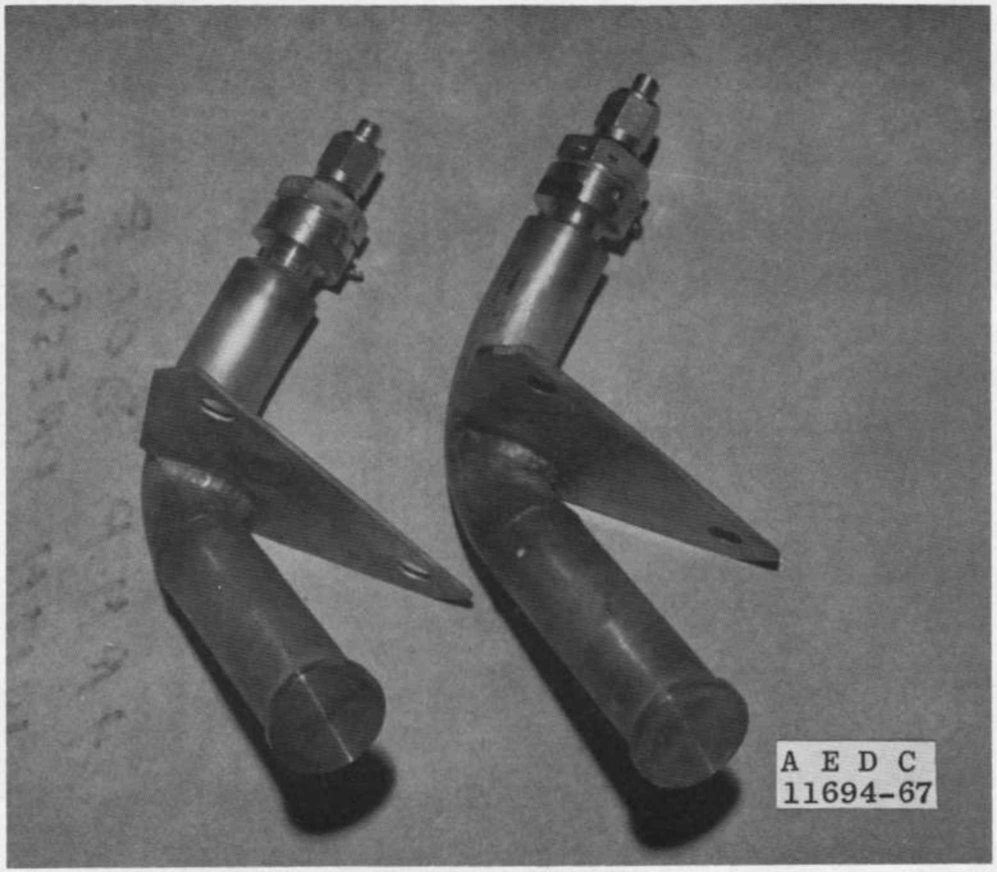


f. Tube 7



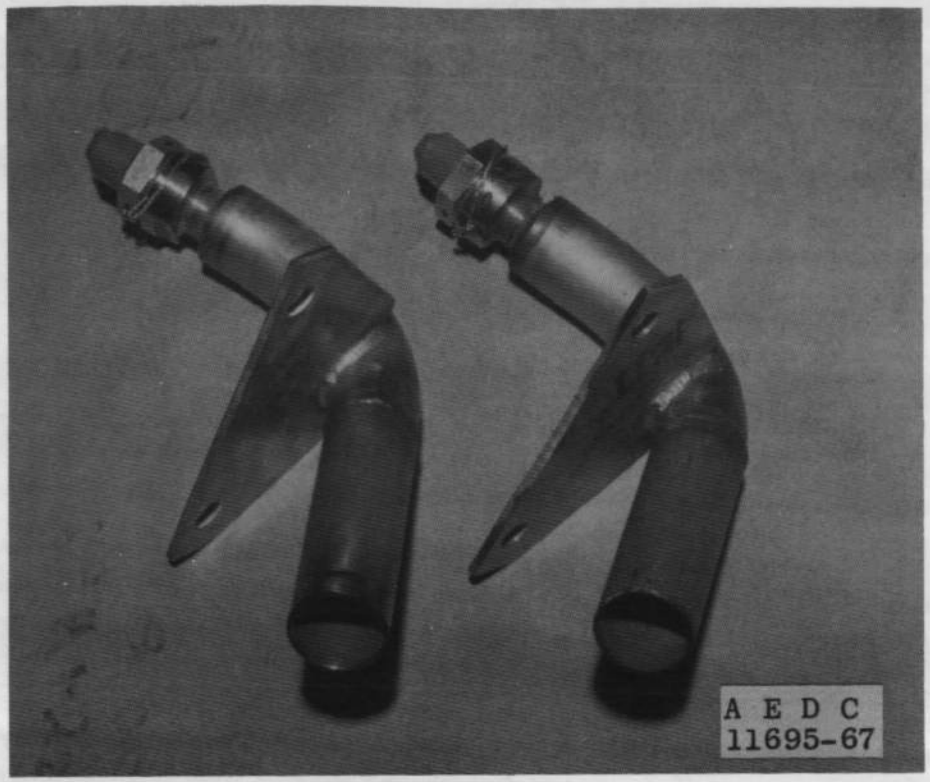
g. Tube 8

Fig. 9 Continued



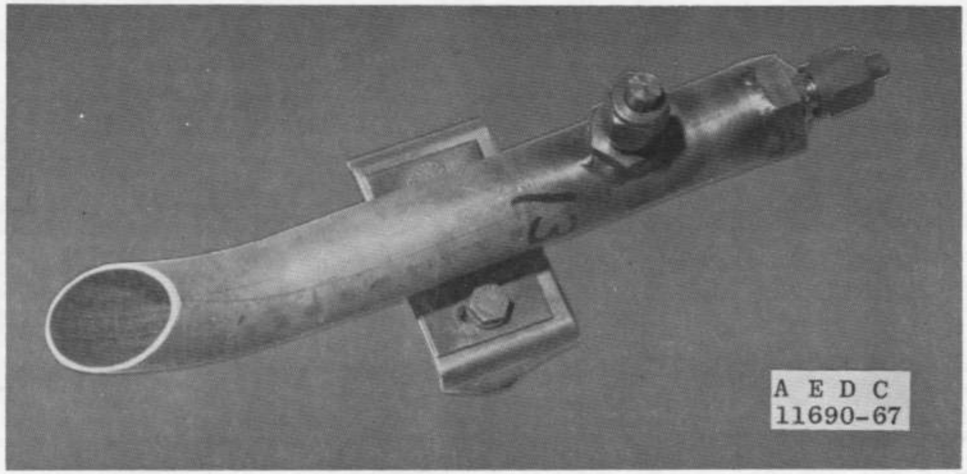
h. Right to Left, Tubes 9 and 10

Fig. 9 Continued

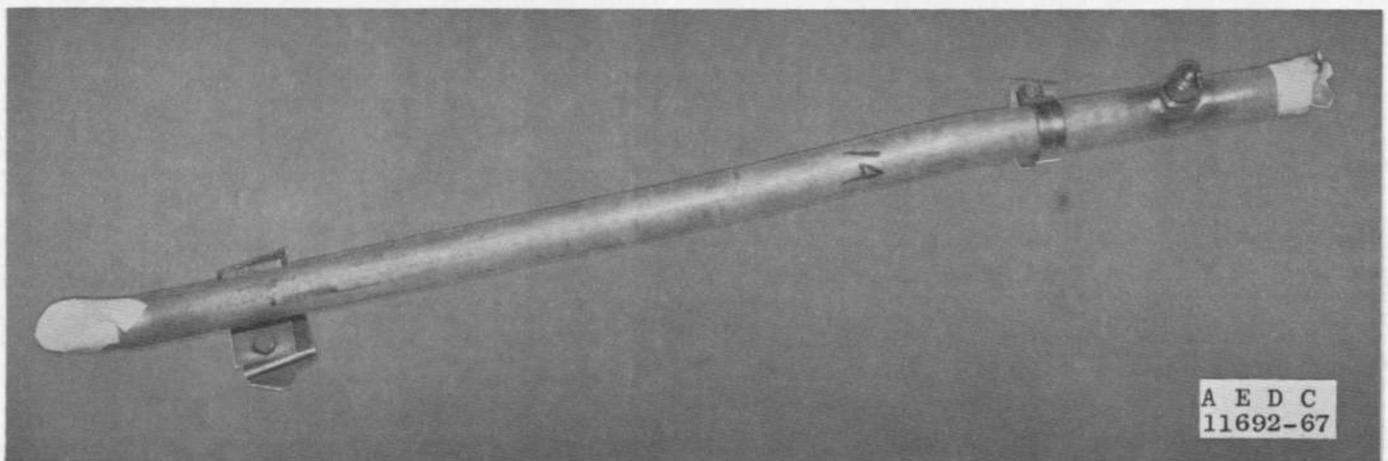


i. Right to Left, Tubes 11 and 12

Fig. 9 Continued



j. Tube 13



k. Tube 14

Fig. 9 Concluded

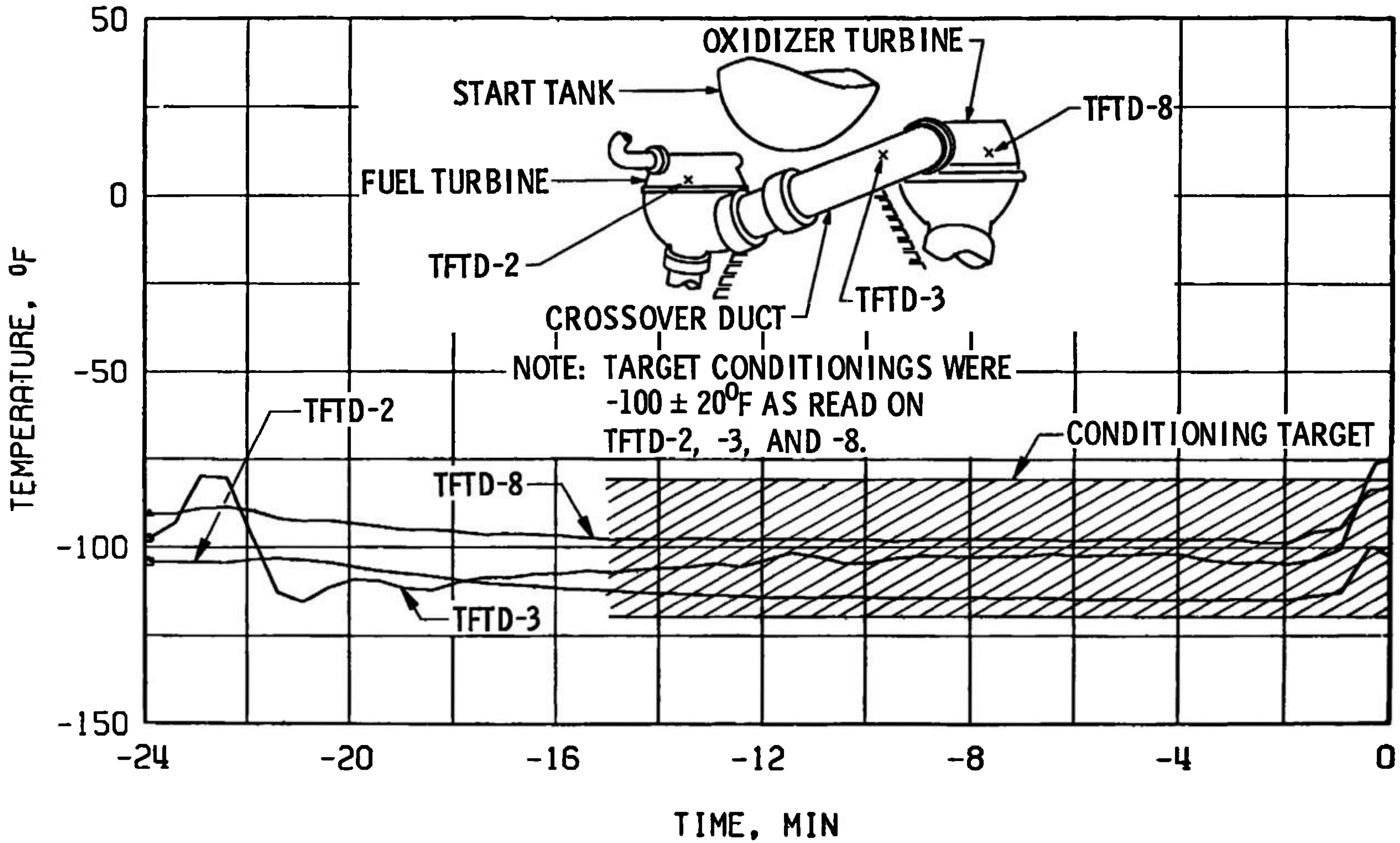
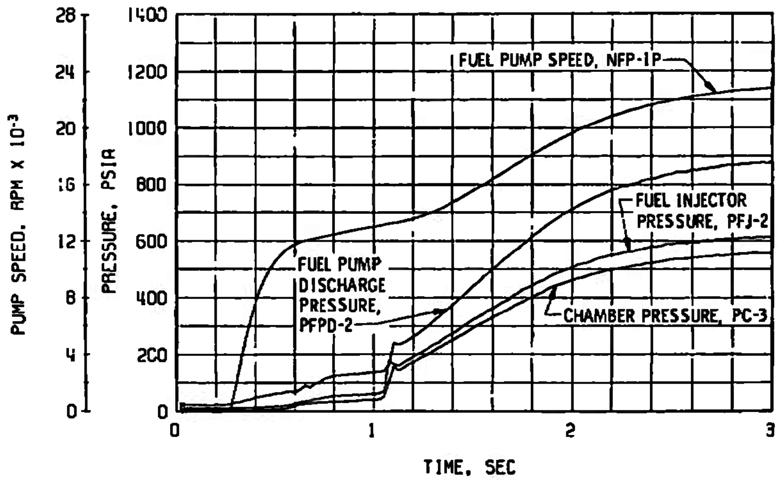
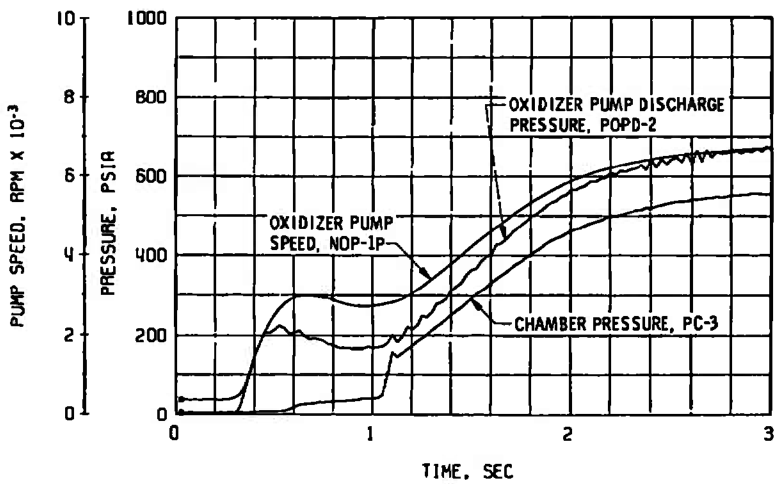


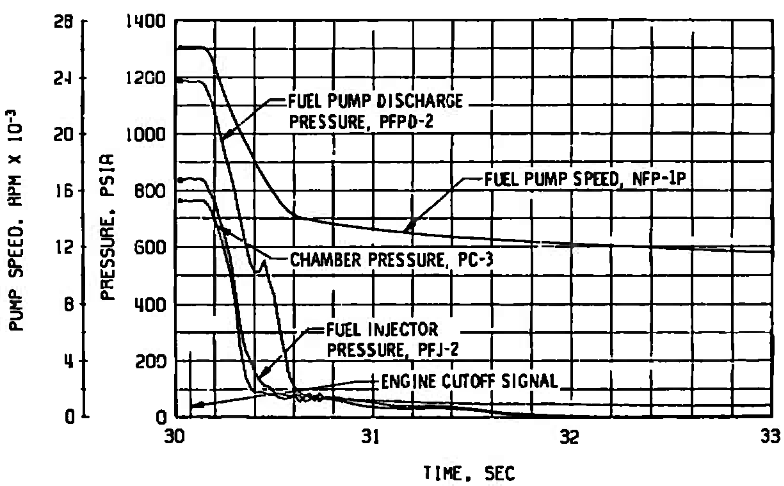
Fig. 10 Thermal Conditioning History of Crossover Duct, Firing 08A



a. Thrust Chamber Fuel System, Start

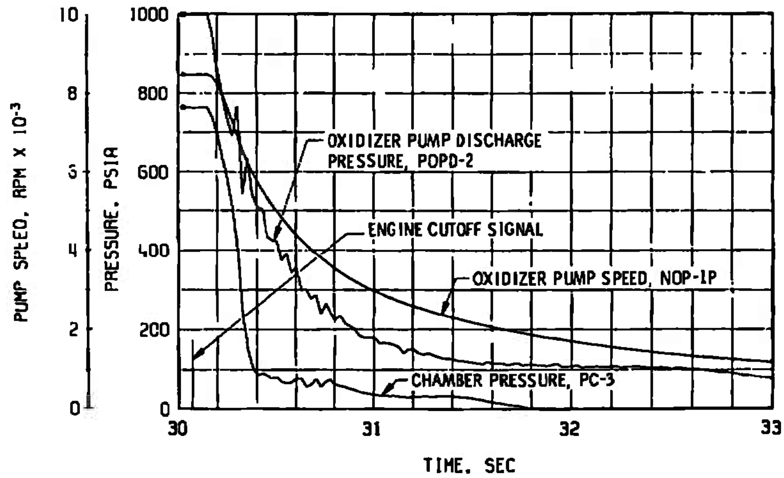


b. Thrust Chamber Oxidizer System, Start

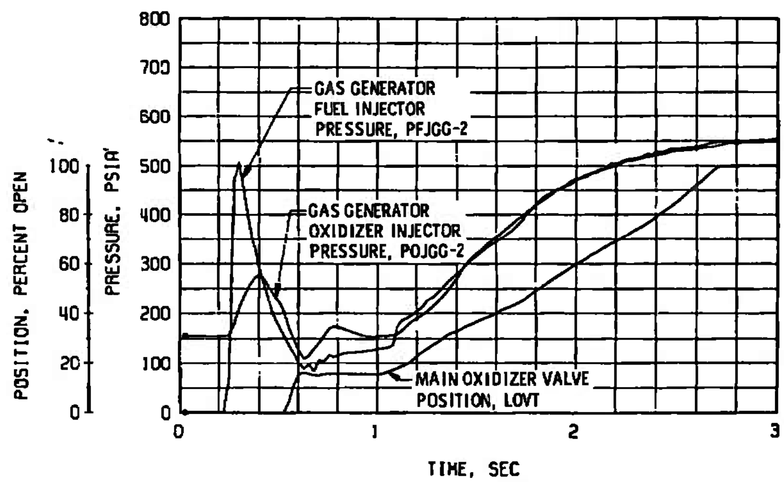


c. Thrust Chamber Fuel System, Shutdown

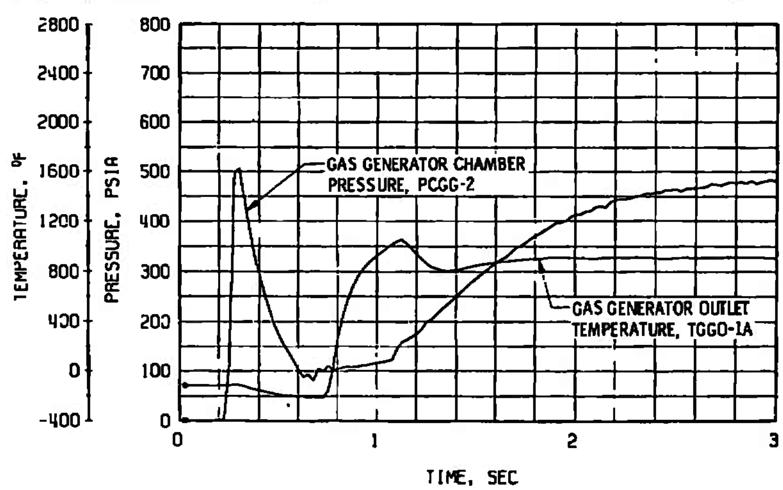
Fig. 11 Engine Transient Operation, Firing 08A



d. Thrust Chamber Oxidizer System, Shutdown

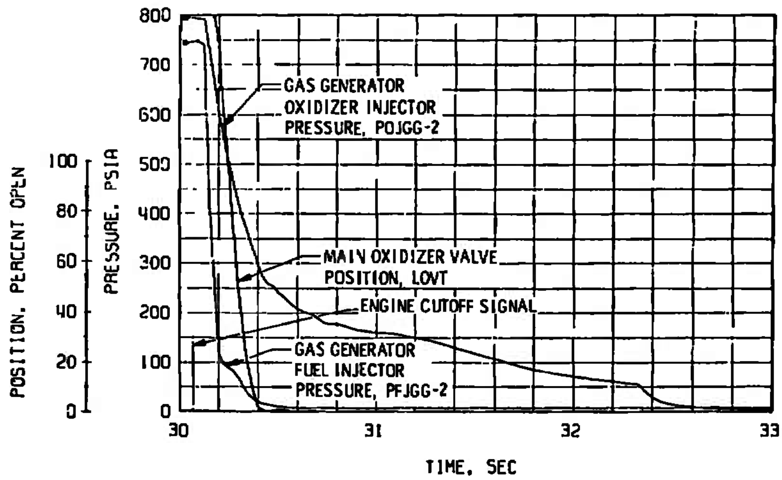


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

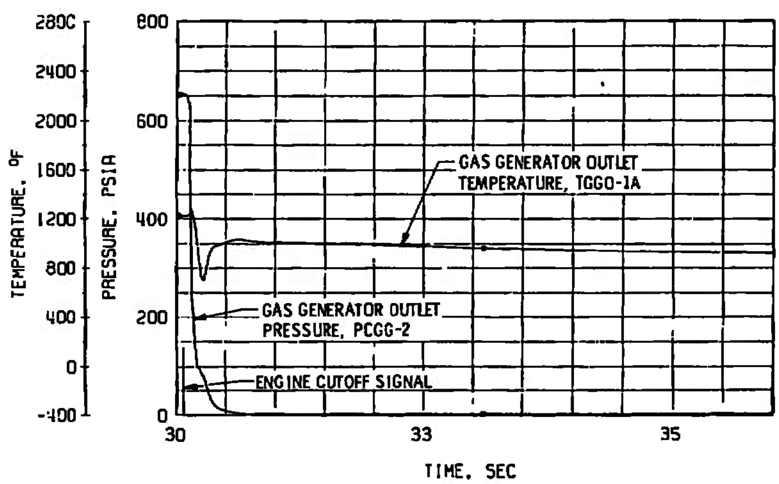


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 11 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 11 Concluded

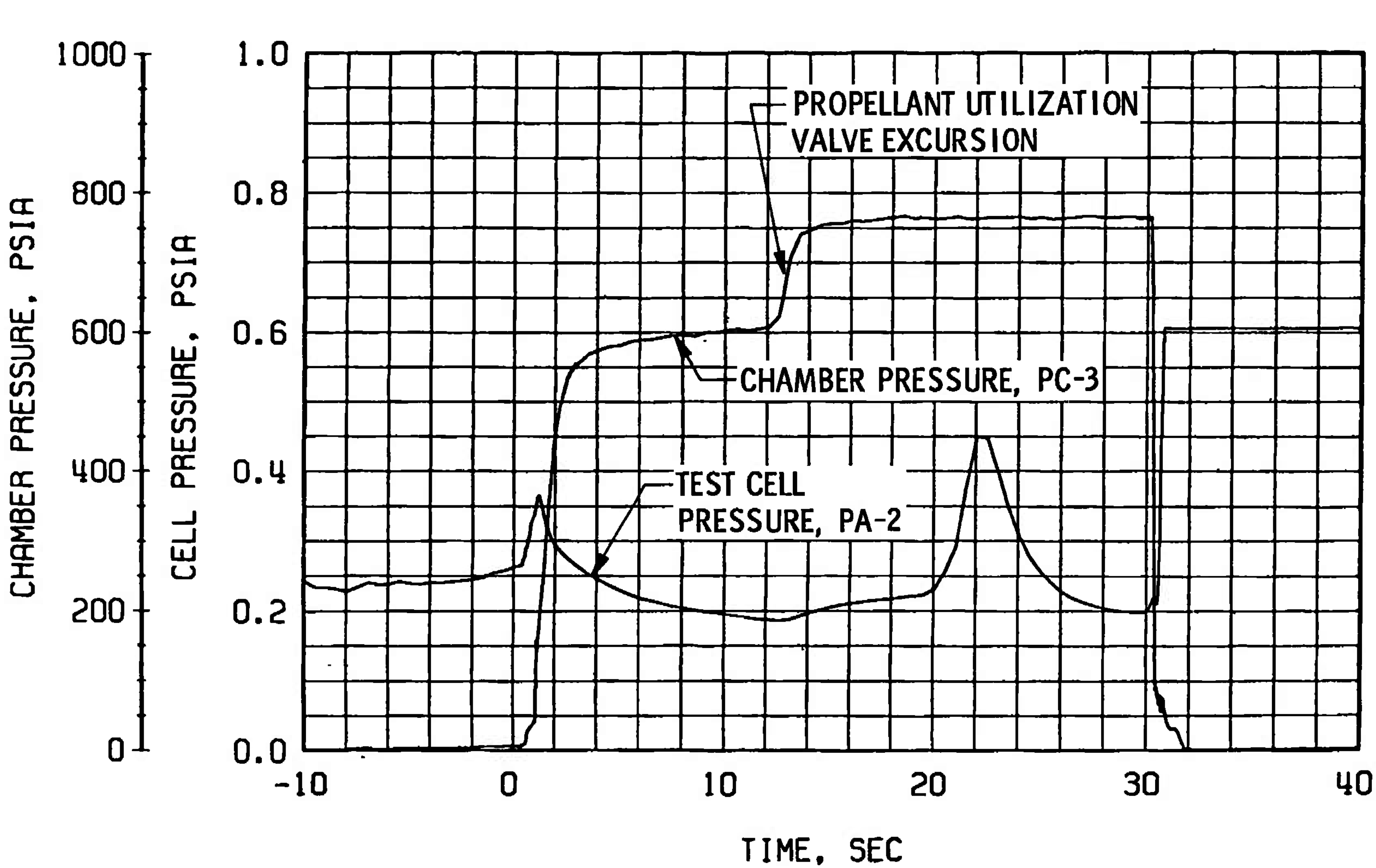


Fig. 12 Engine Ambient and Combustion Chamber Pressures, Firing 08A

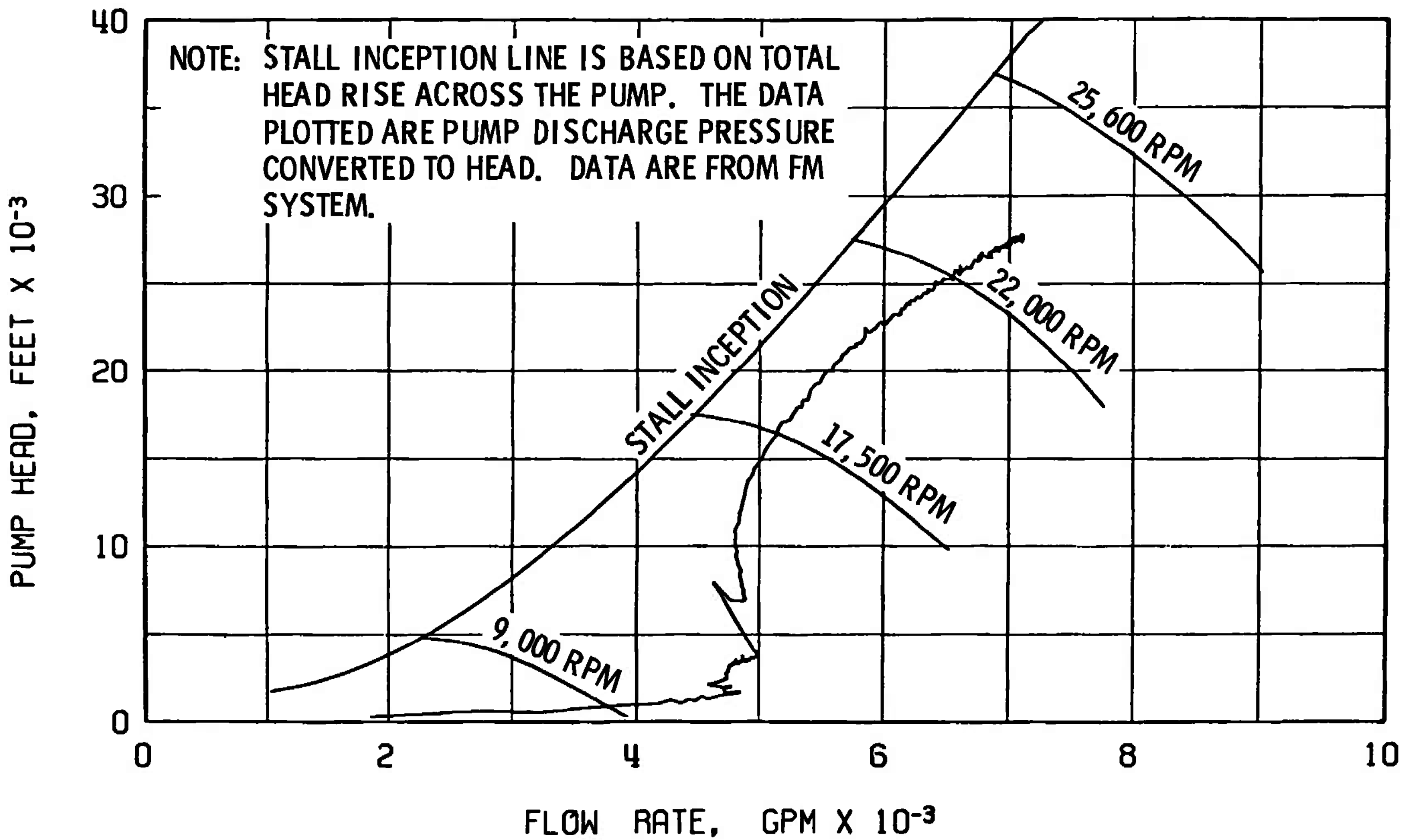
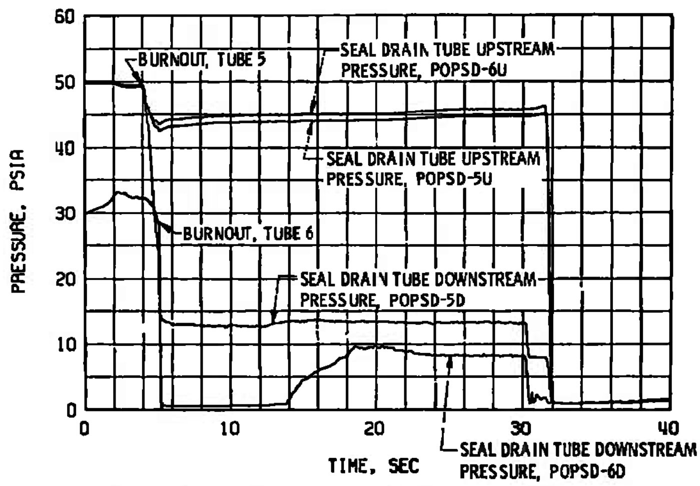
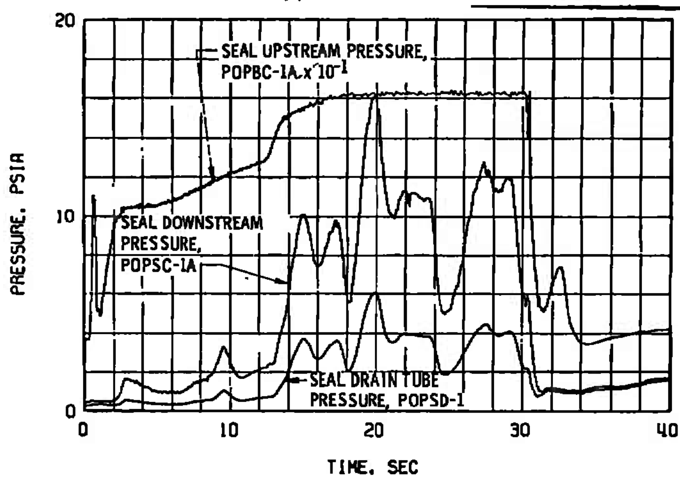


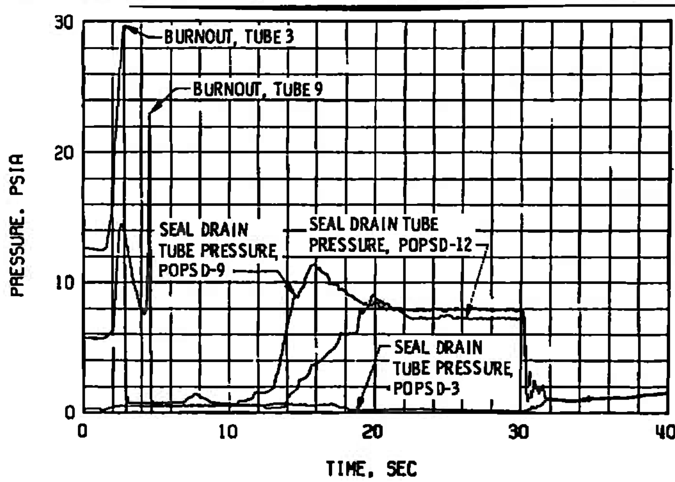
Fig. 13 Fuel Pump Start Transient Performance, Firing 08A



a. Drain Tubes Supplied with Gaseous Oxygen



b. Modified Oxidizer Pump Primary Seal Drain, Tube 1



c. Typical Seal Drain Burnout Tube Performance

Fig. 14 Oxidizer Pump Primary Seal Drain Performance

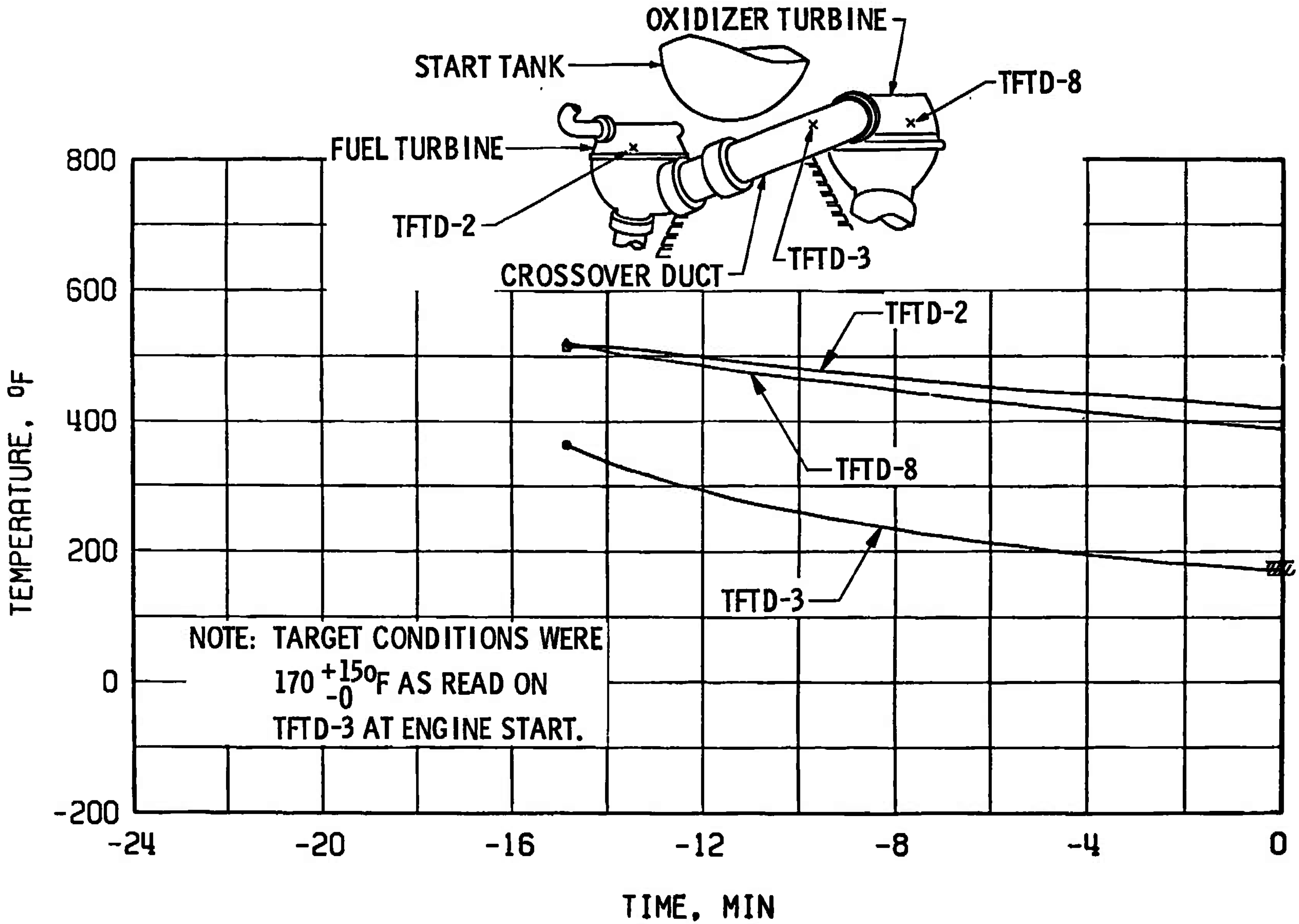
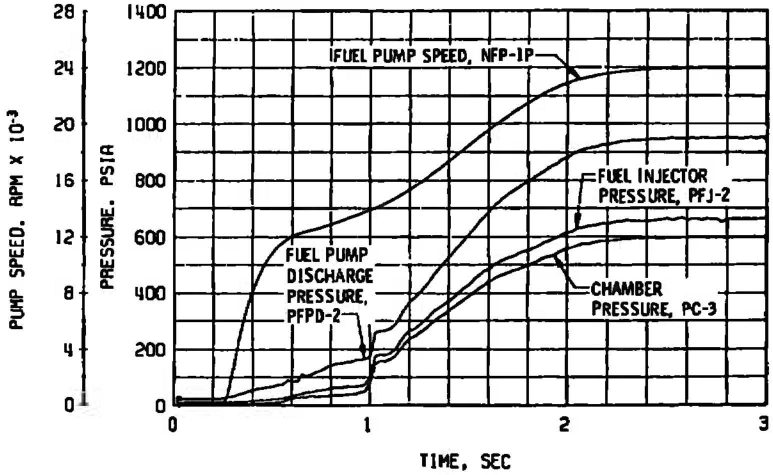
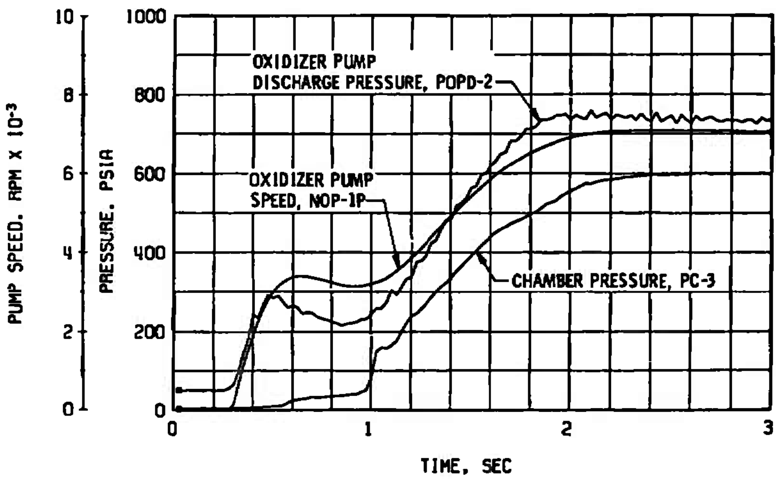


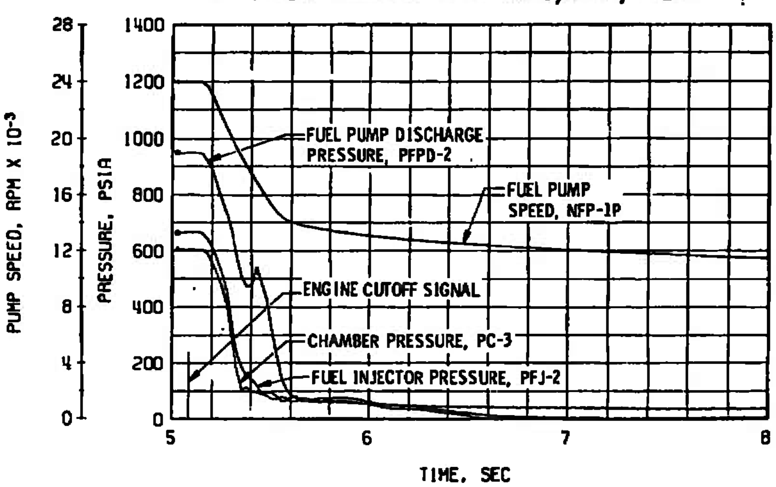
Fig. 15 Thermal Conditioning History of Crossover Duct, Firing 08A



a. Thrust Chamber Fuel System, Start

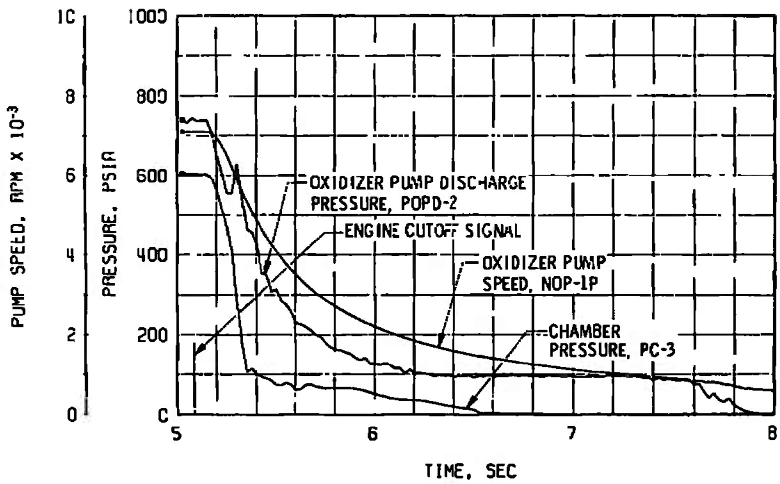


b. Thrust Chamber Oxidizer System, Start

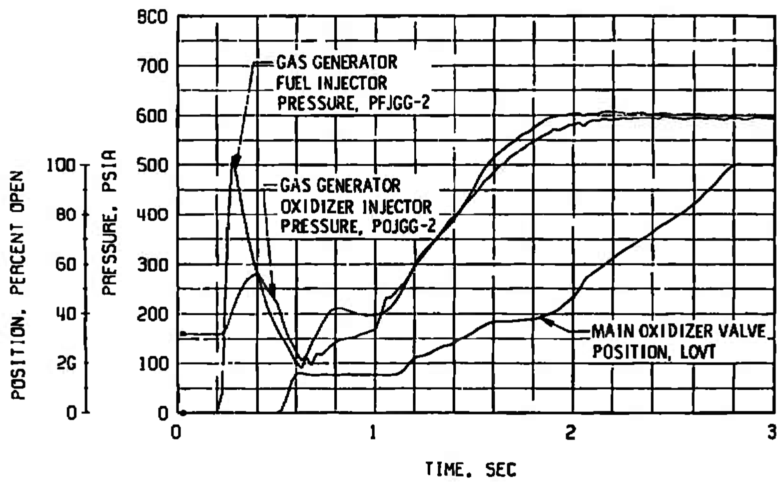


c. Thrust Chamber Fuel System, Shutdown

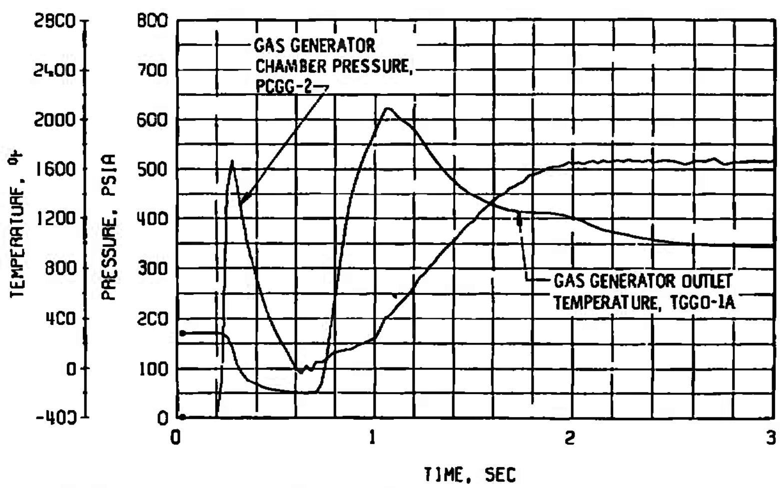
Fig. 16 Engine Transient Operation, Firing 08B



d. Thrust Chamber Oxidizer System, Shutdown

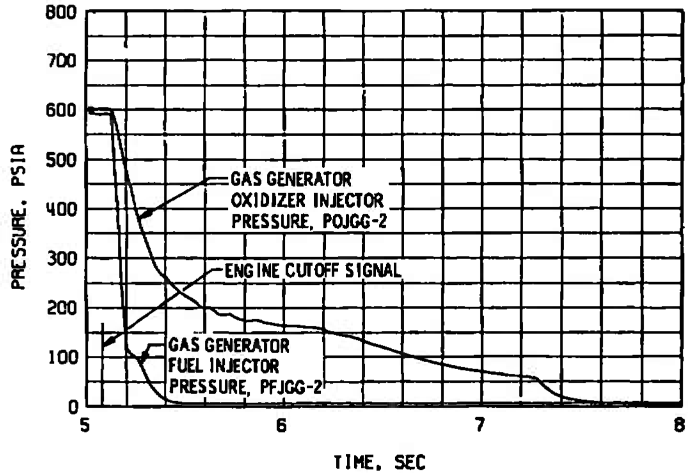


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

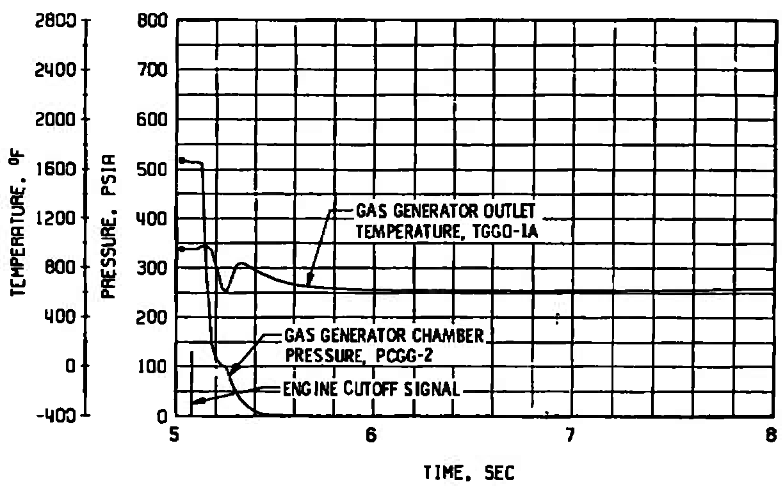


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 16 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 16 Concluded

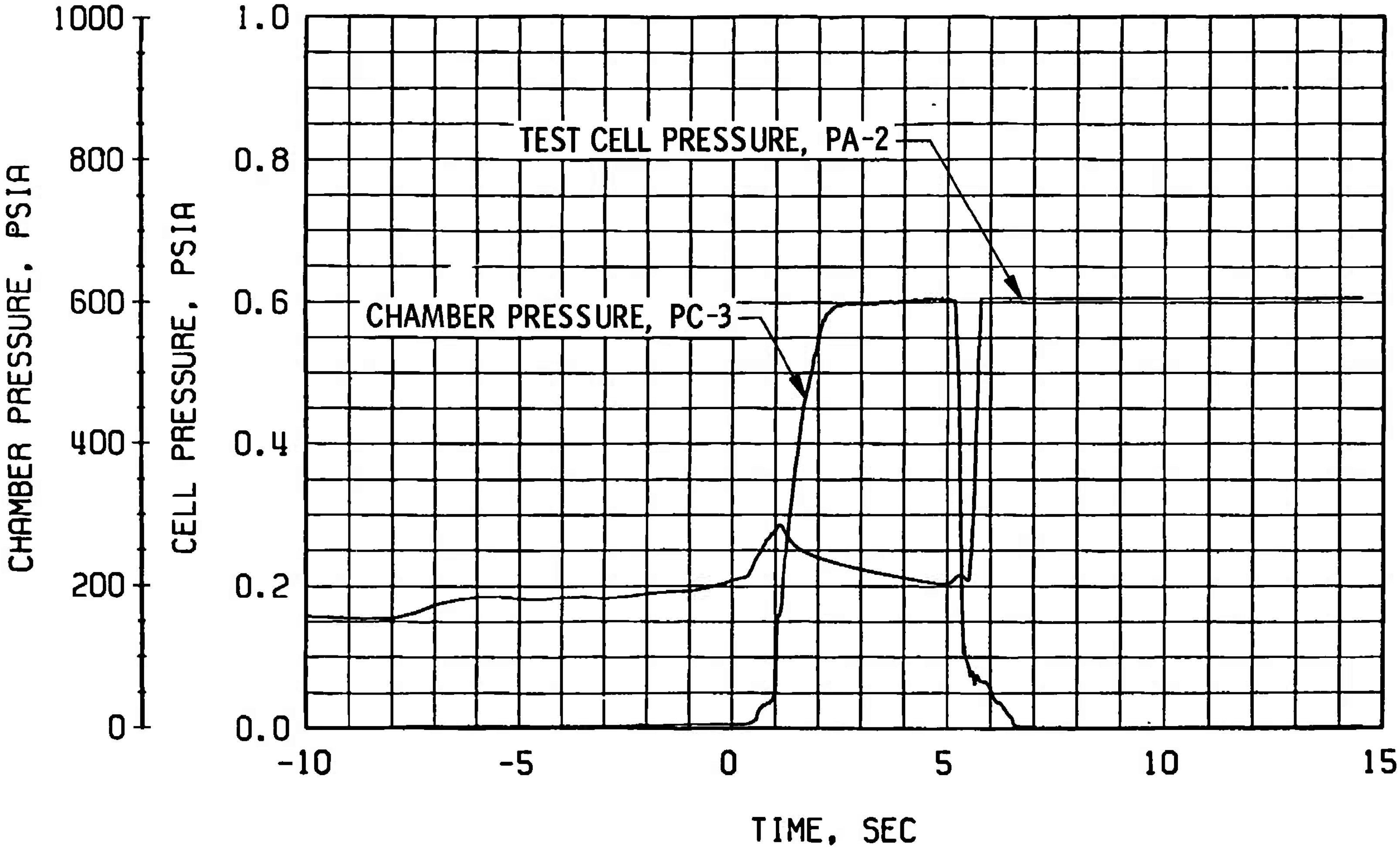


Fig. 17 Engine Ambient and Combustion Chamber Pressures, Firing 08B

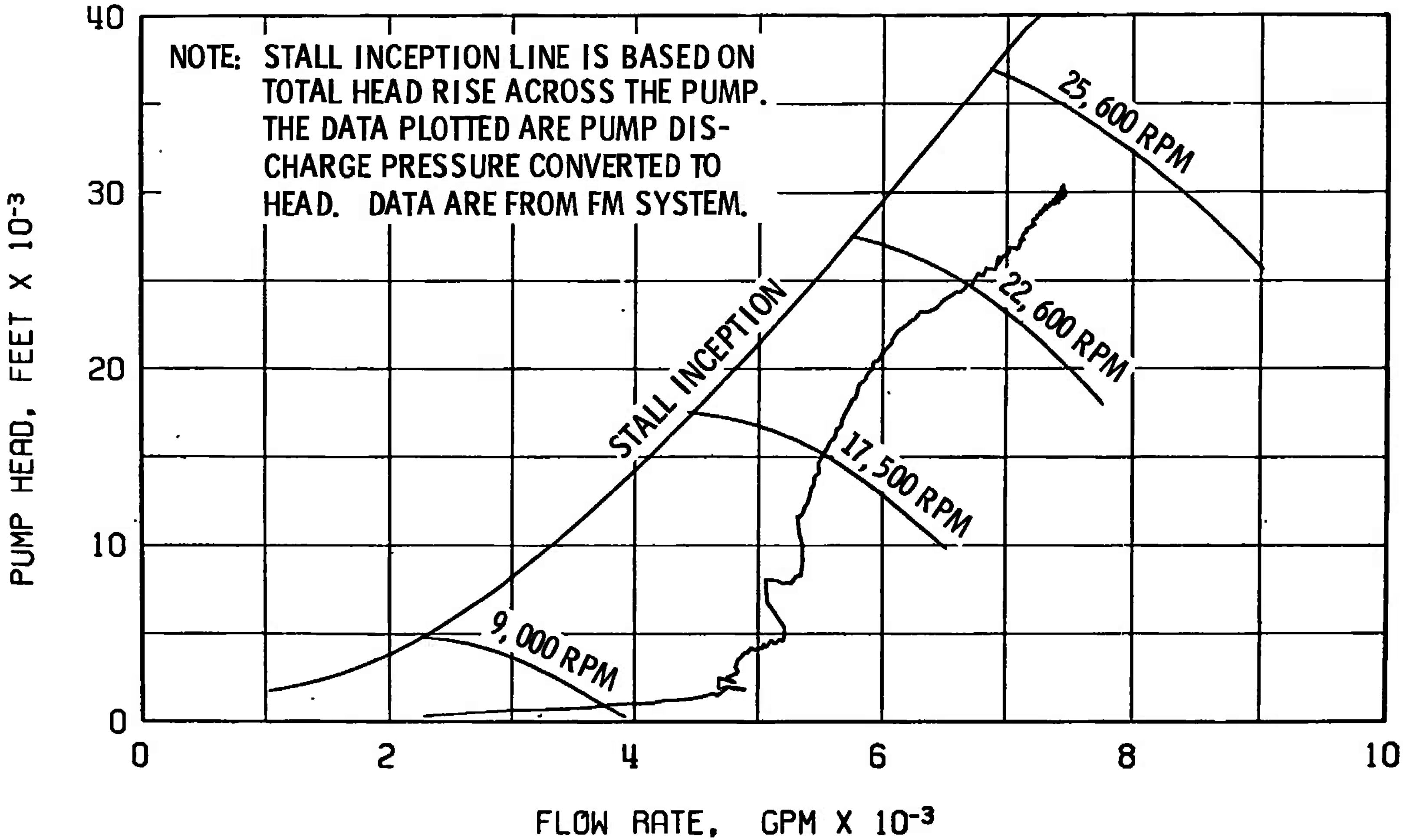
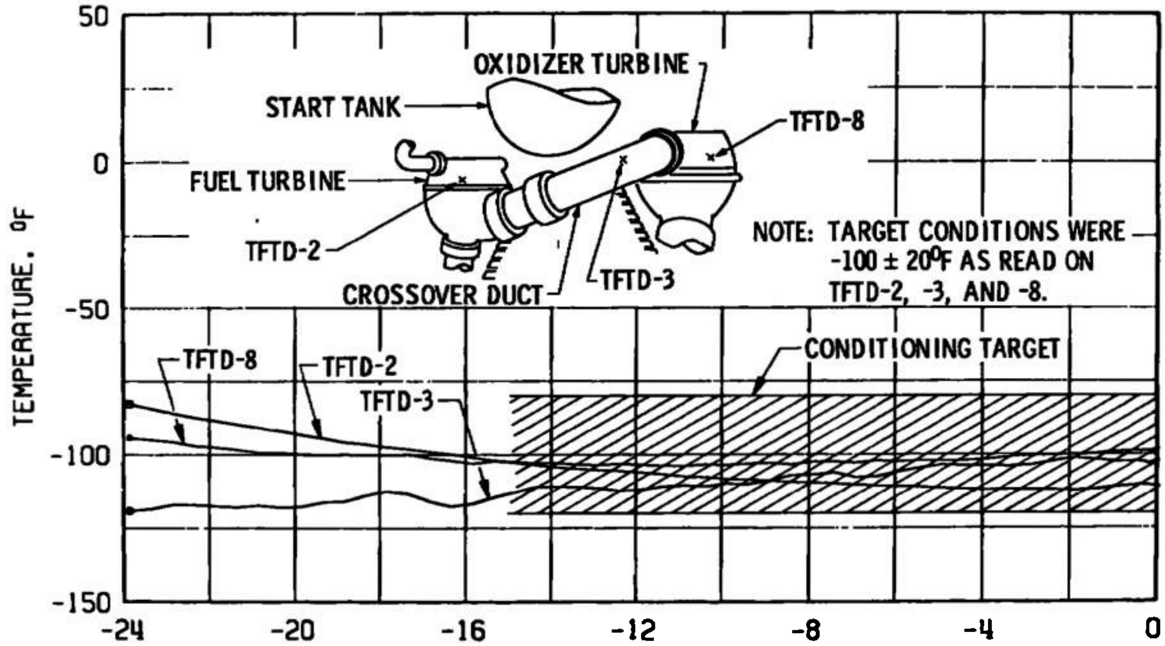
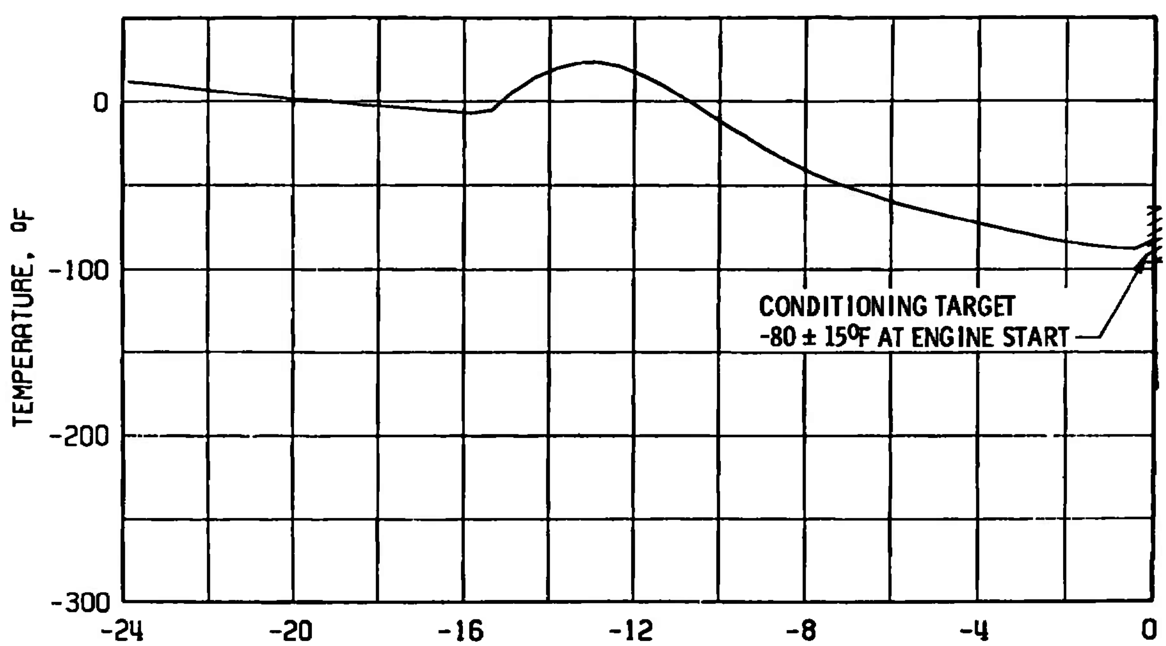


Fig. 18 Fuel Pump Start Transient Performance, Firing 08B

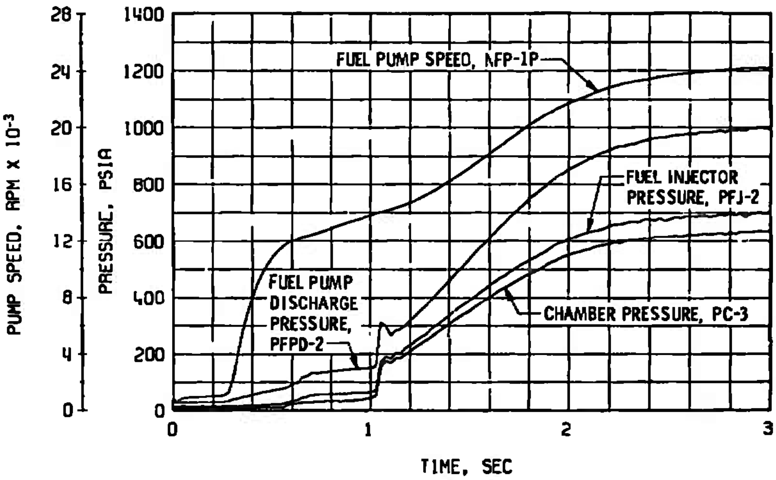


a. Crossover Duct, TFTD

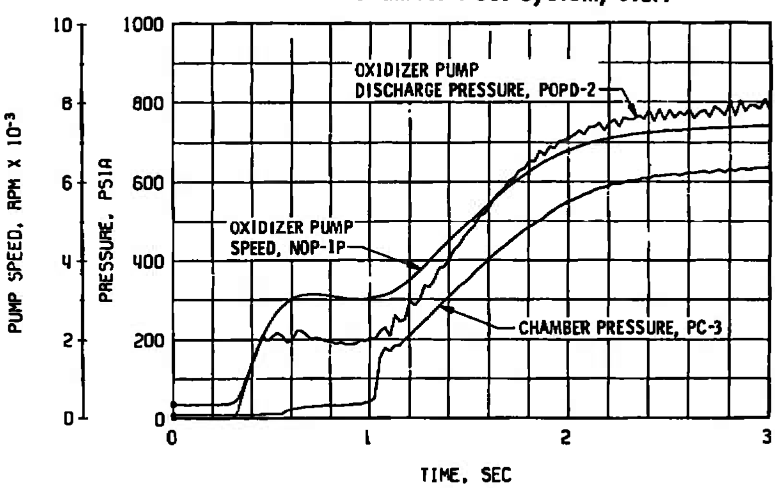


b. Thrust Chamber Throat, TSC2-19

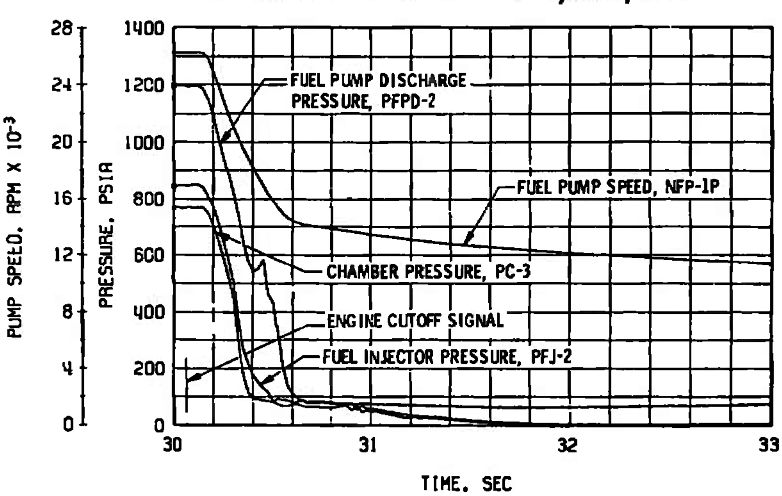
Fig. 19 Thermal Conditioning History of Engine Components, Firing 08C



a. Thrust Chamber Fuel System, Start

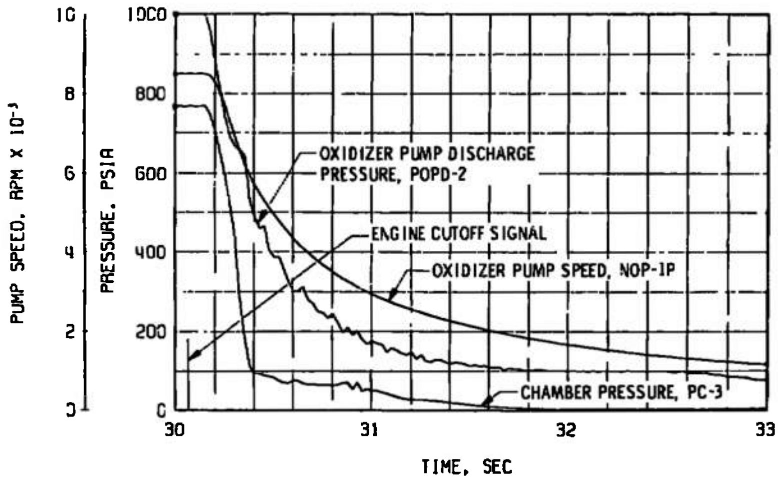


b. Thrust Chamber Oxidizer System, Start

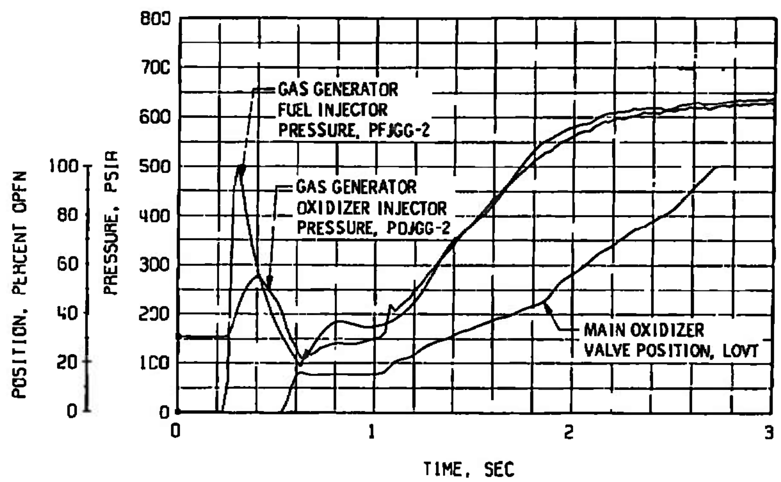


c. Thrust Chamber Fuel System, Shutdown

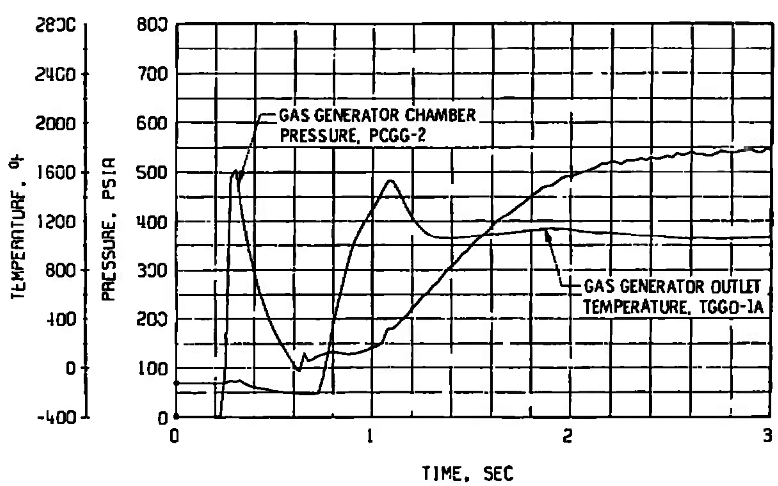
Fig. 20 Engine Transient Operation, Firing 08C



d. Thrust Chamber Oxidizer System, Shutdown

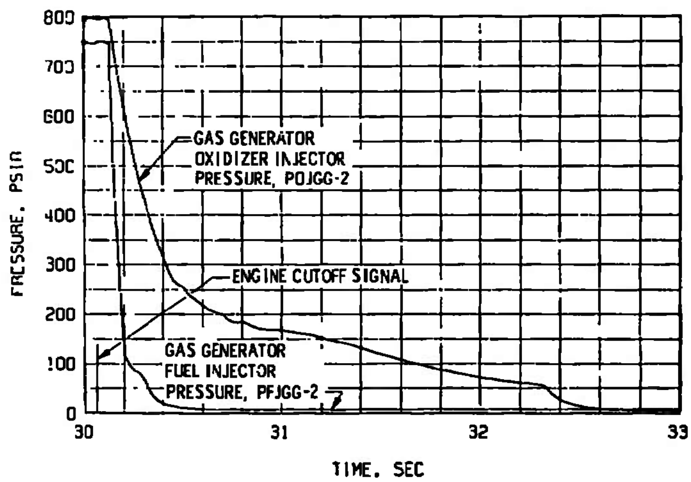


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

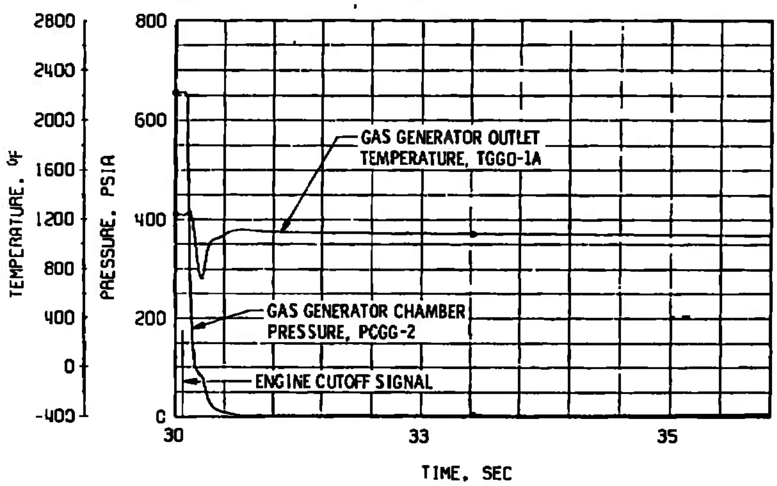


f. Gas Generator Chamber Pressure and Temperature, Start

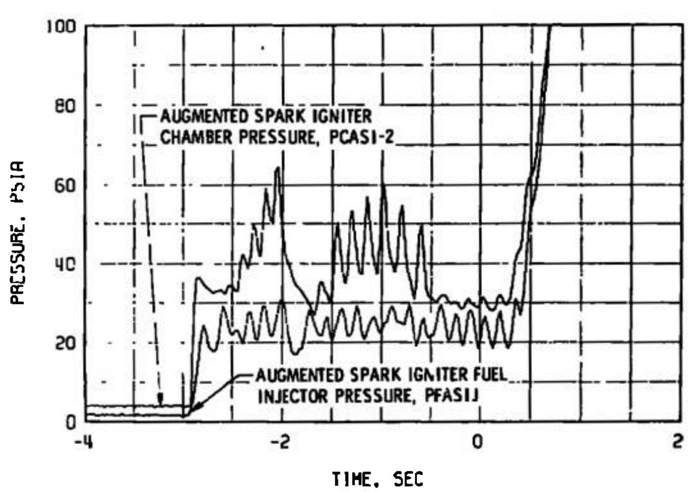
Fig. 20 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown



i. Augmented Spark Igniter Performance

Fig. 20 Concluded

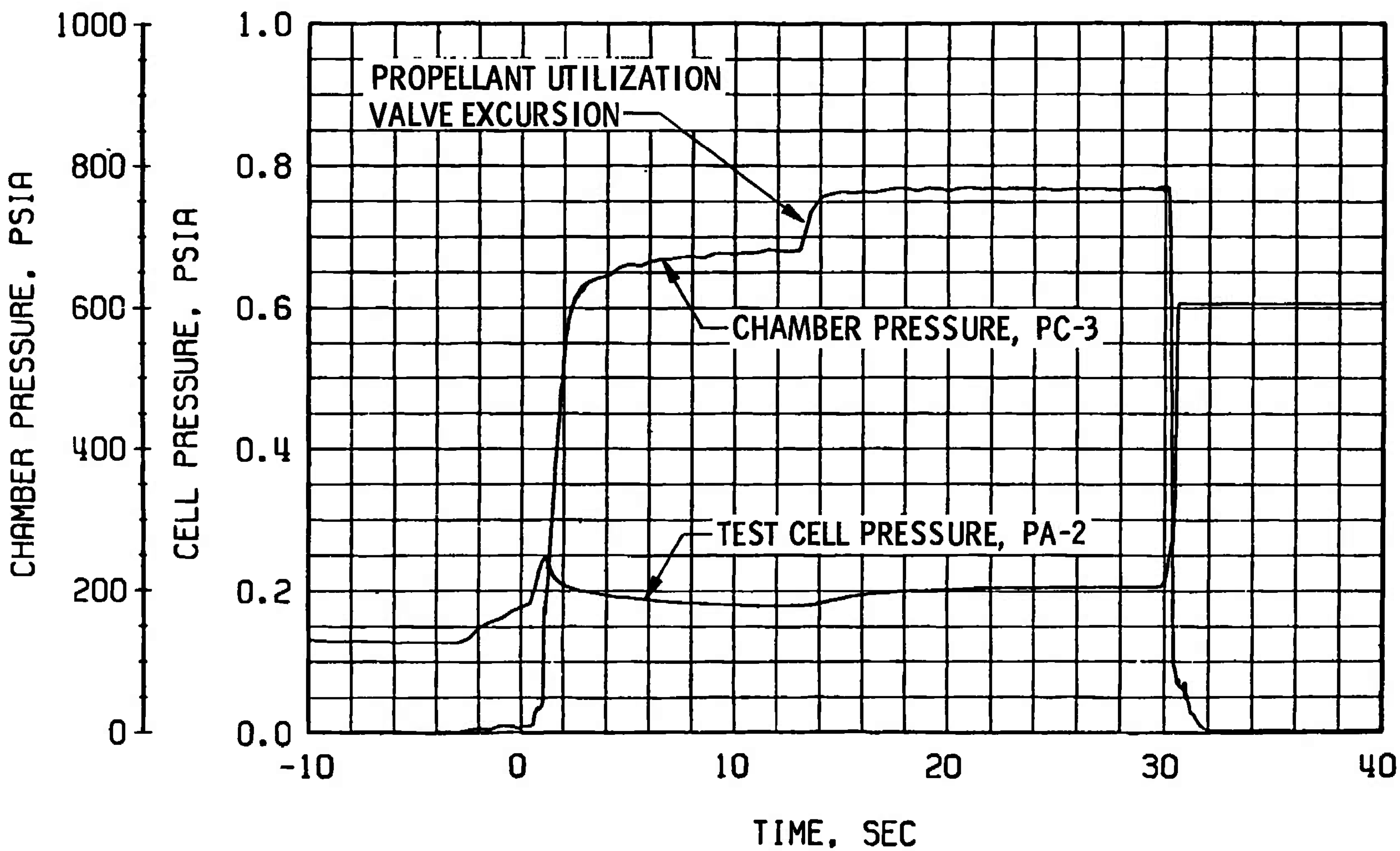


Fig. 21 Engine Ambient and Combustion Chamber Pressures, Firing 08C

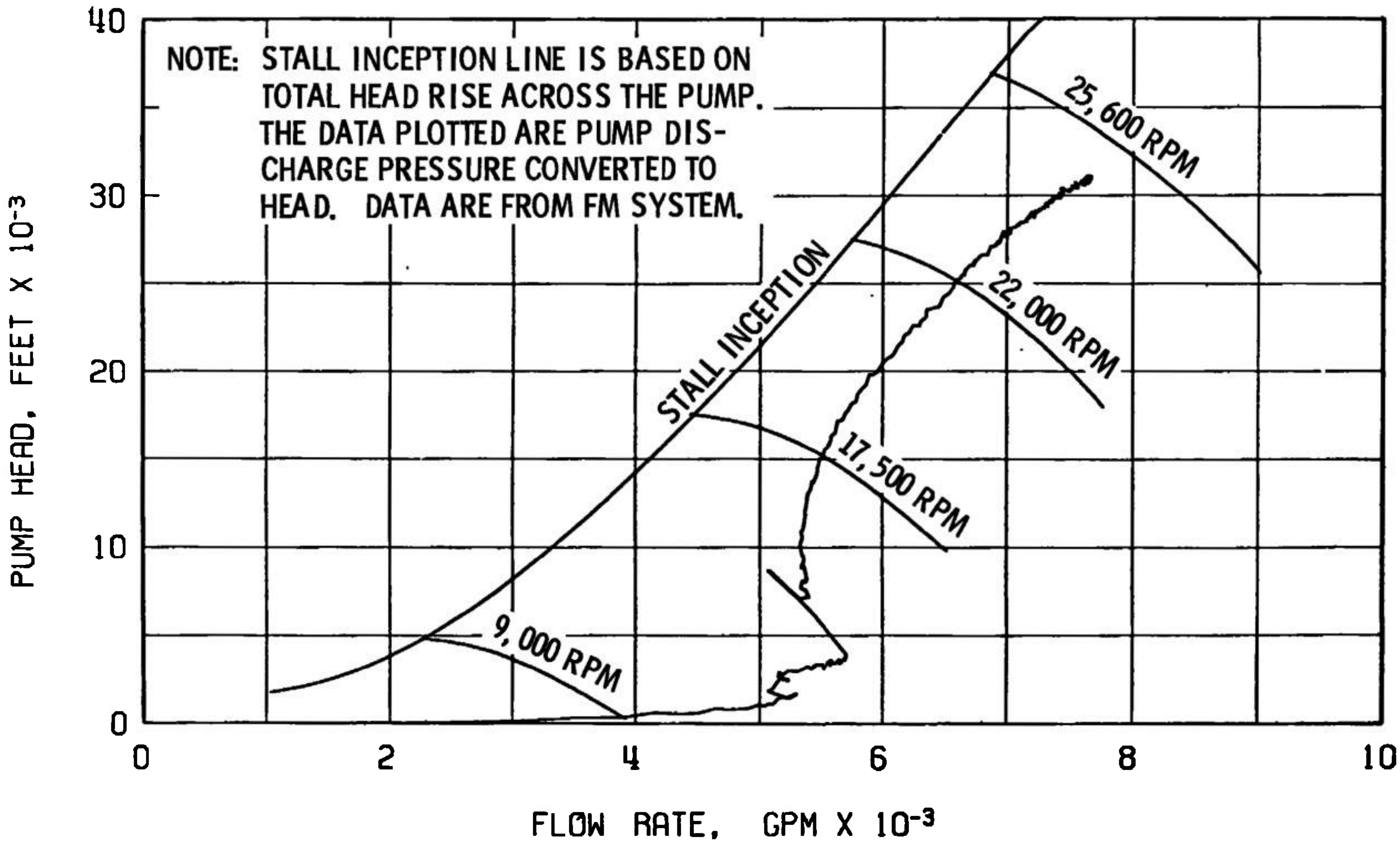


Fig. 22 Fuel Pump Start Transient Performance, Firing 08C

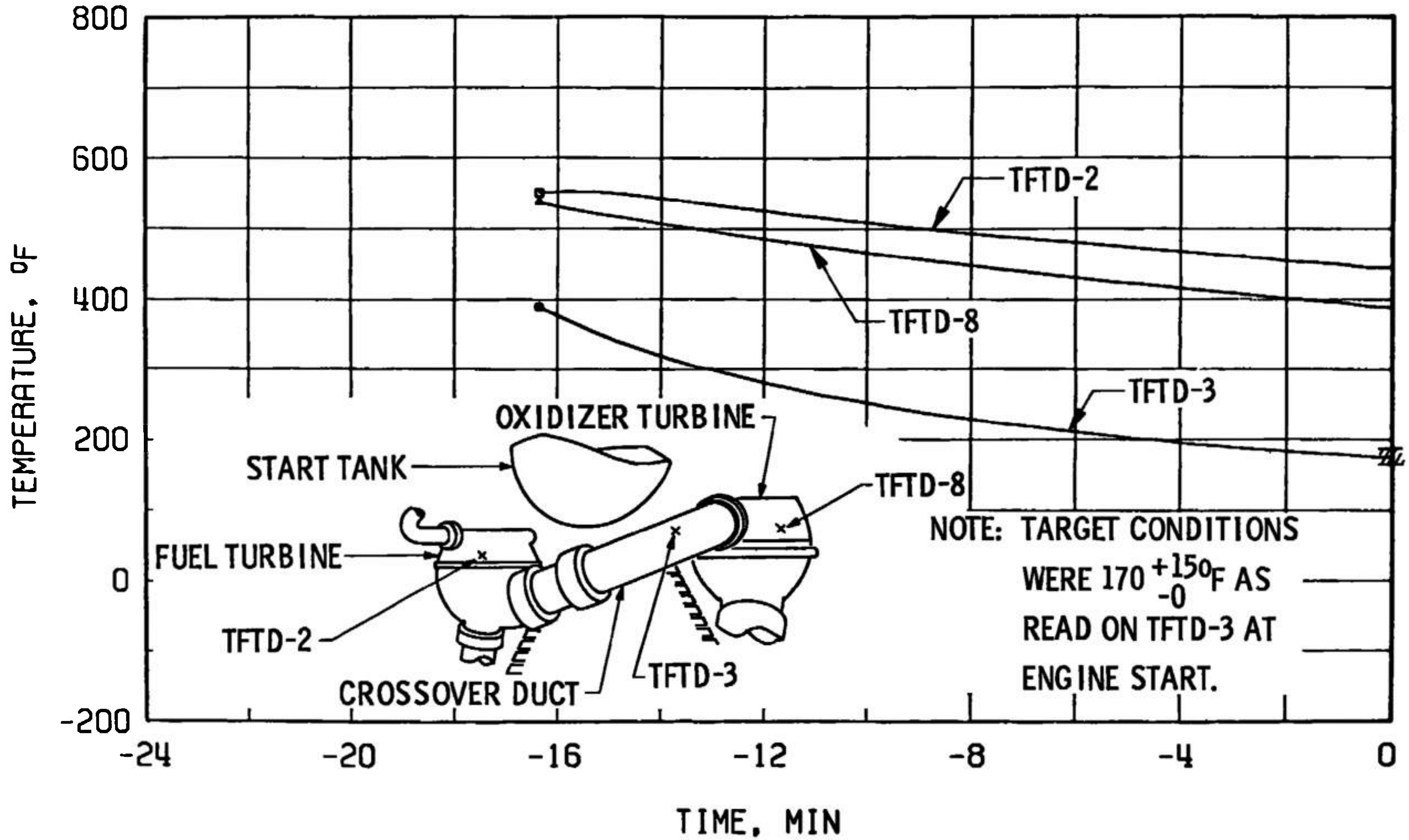
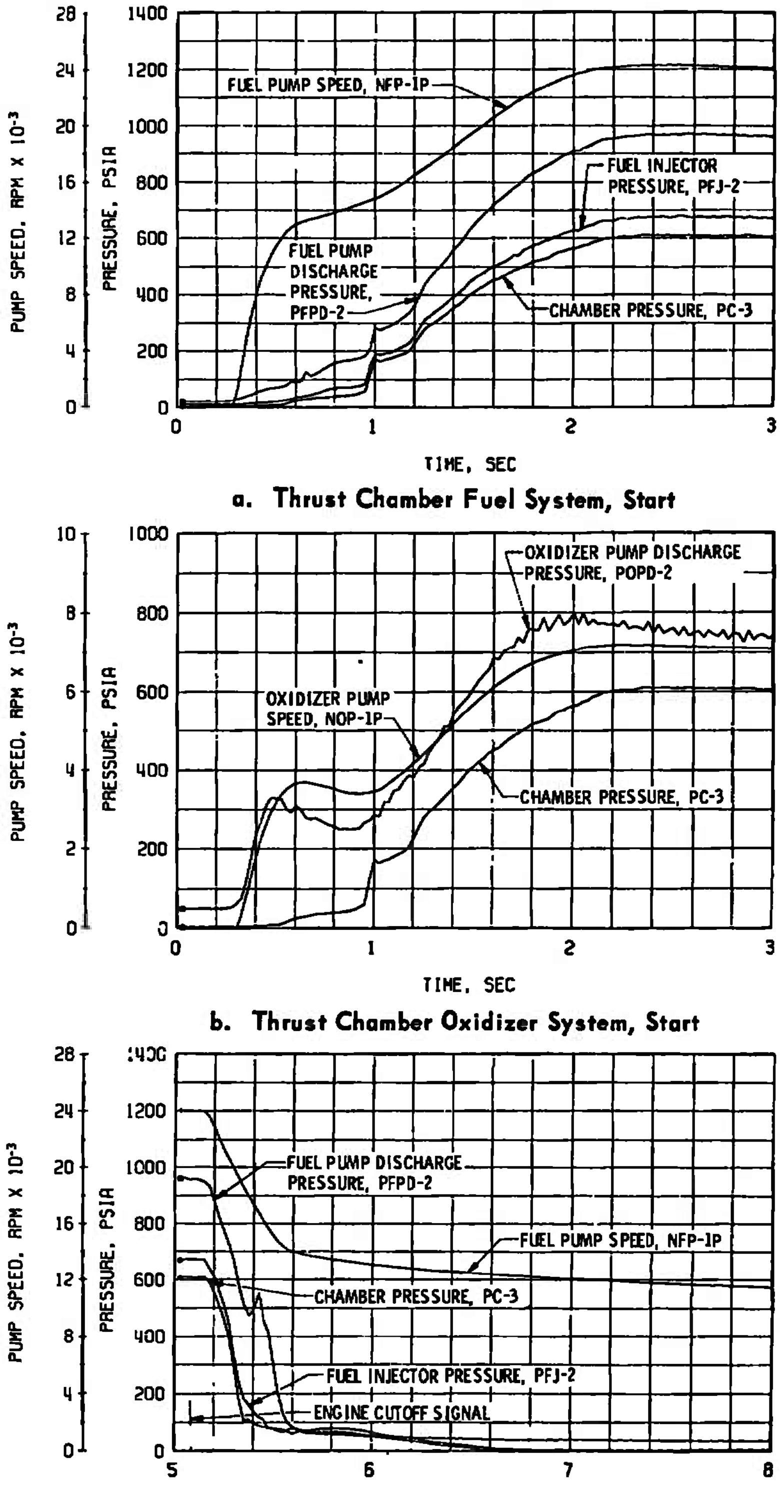


Fig. 23 Thermal Conditioning History of Crossover Duct, Firing 08D

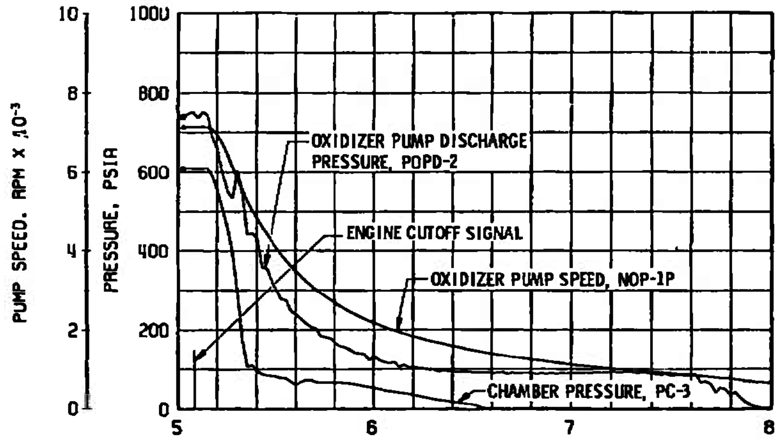


a. Thrust Chamber Fuel System, Start

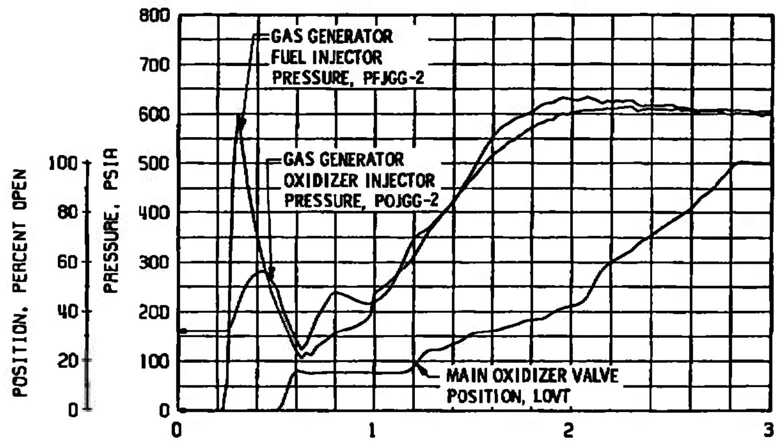
b. Thrust Chamber Oxidizer System, Start

c. Thrust Chamber Fuel System, Shutdown

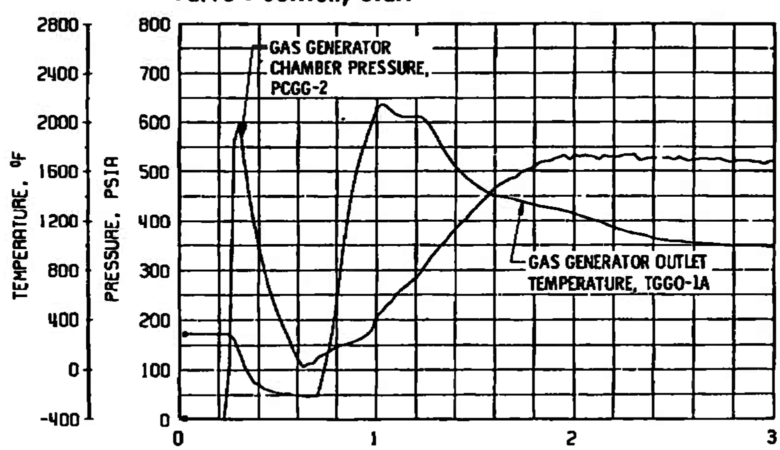
Fig. 24 Engine Transient Operation, Firing 08D



d. Thrust Chamber Oxidizer System, Shutdown

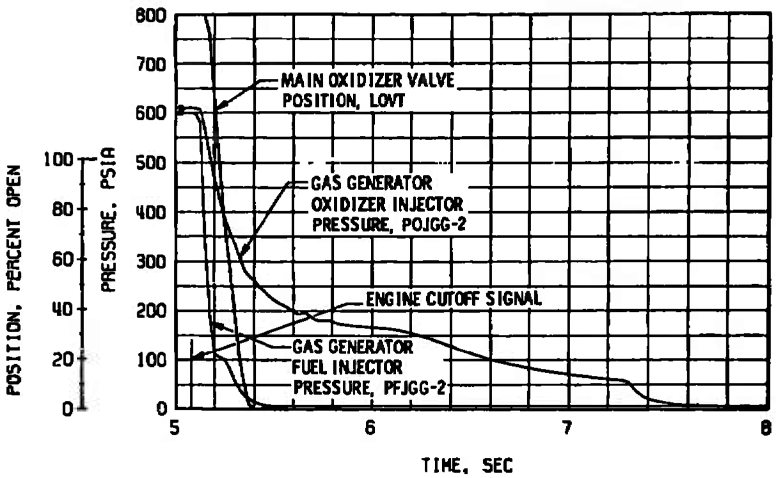


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

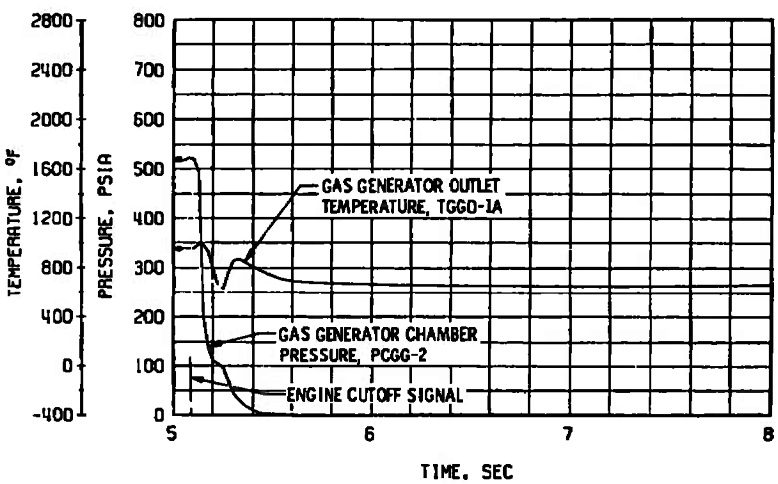


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 24 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 24 Concluded

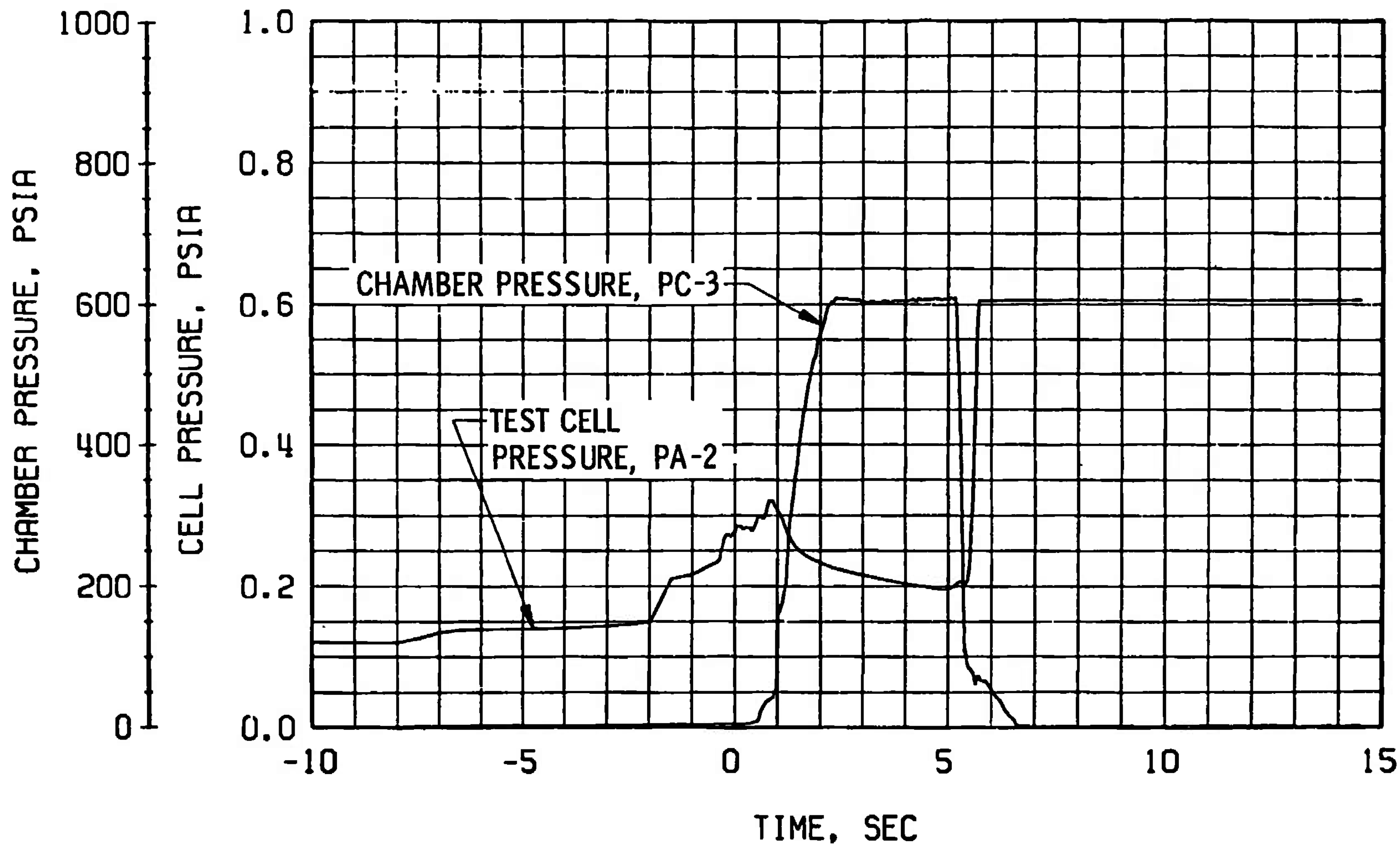
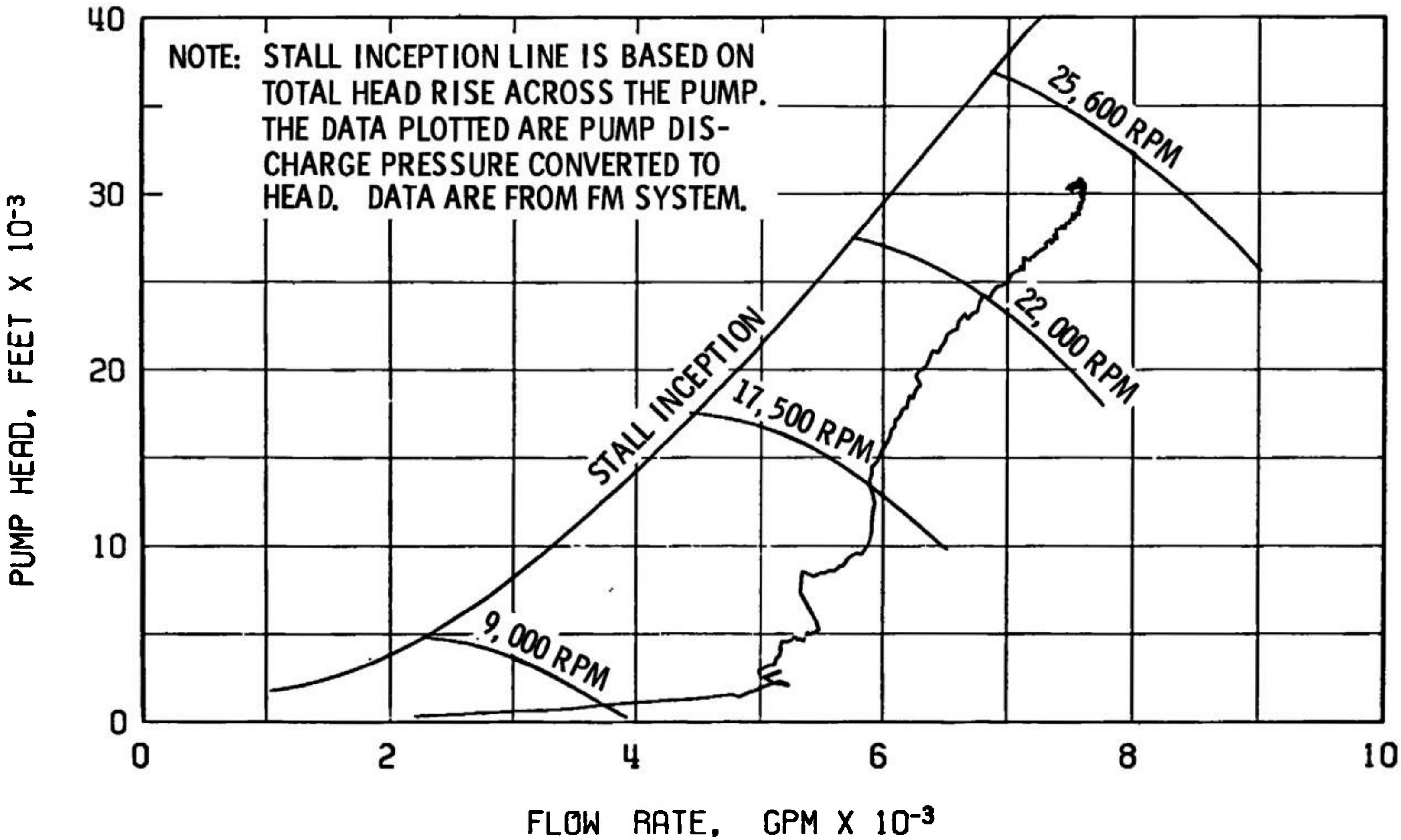
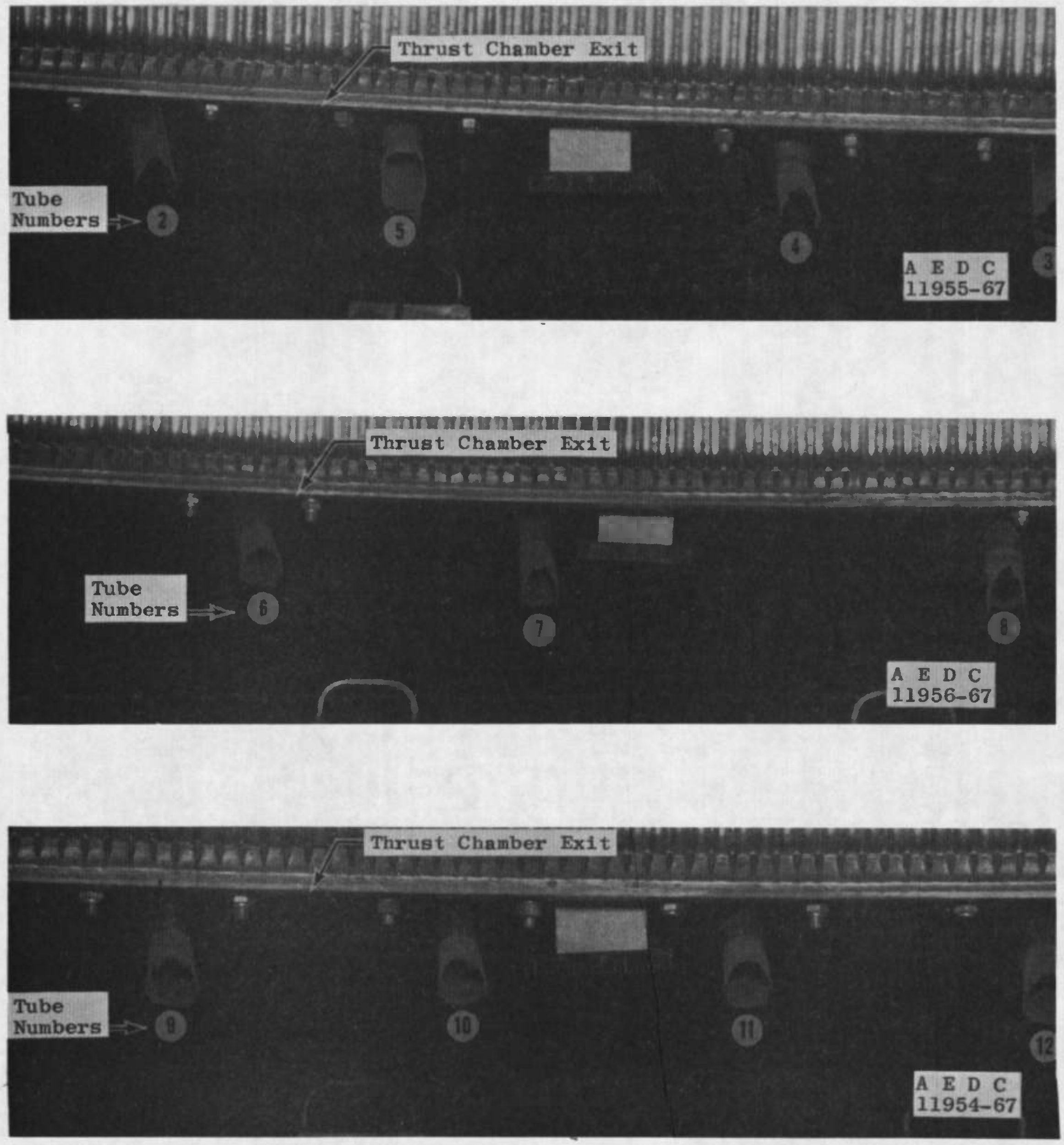


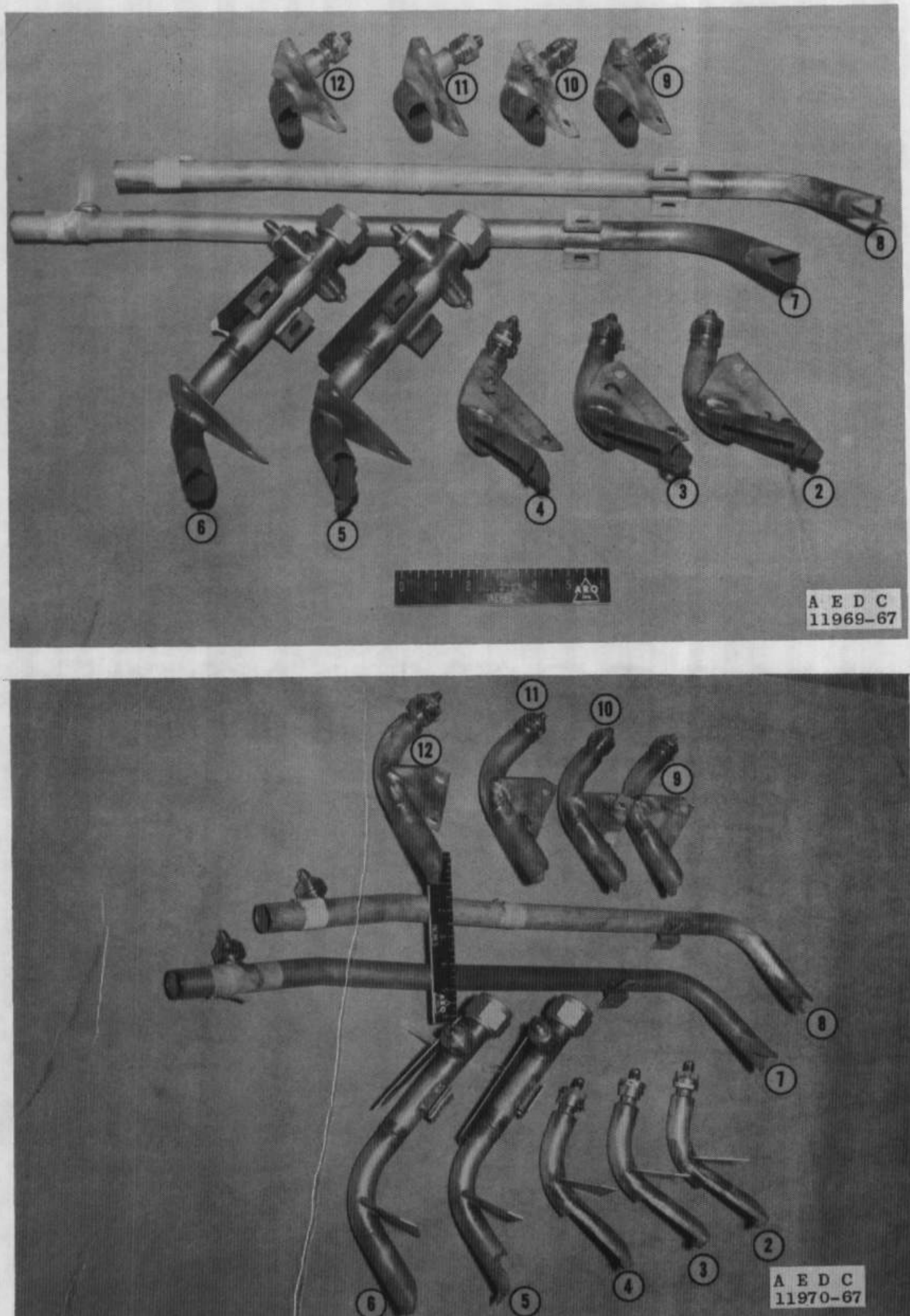
Fig. 25 Engine Ambient and Combustion Chamber Pressures, Firing 08D


NOTE: STALL INCEPTION LINE IS BASED ON TOTAL HEAD RISE ACROSS THE PUMP. THE DATA PLOTTED ARE PUMP DISCHARGE PRESSURE CONVERTED TO HEAD. DATA ARE FROM FM SYSTEM.
STALL INCEPTION
25,600 RPM
22,000 RPM
17,500 RPM
9,000 RPM
PUMP HEAD, FEET X 10^{-3}
FLOW RATE, GPM X 10^{-3}
0
10
20
30
40
0
2
4
6
8
10



a. Before Removal from Thrust Chamber

Fig. 27 Post-Test Photographs of Oxidizer Pump Primary Seal Drain Tubes



b. View after Removal from Thrust Chamber; Post-Test Photograph of Seal Drain Burnout Tubes

Fig. 27 Concluded

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4076553
Thrust Chamber Injector Assembly	208021-11	4084917
Fuel Turbopump Assembly	459000-181	4062085
Oxidizer Turbopump Assembly	458175-71	6623549
Start Tank	303439	0064
Augmented Spark Igniter	206280-21	3661349
Gas Generator Fuel Injector and Combustor	308360-11	2008734
Pneumatic Control Assembly	558130-41	4092999
Electrical Control Package	502670-11	4081748
Primary Flight Instrumentation Package	703685	4078716
Auxiliary Flight Instrumentation Package	703680	4078718
Main Fuel Valve	409120	4056924
Main Oxidizer Valve	411031	4089563
Gas Generator Control Valve	309040	4074190
Start Tank Discharge Valve	306875	4079062
Oxidizer Turbine Bypass Valve	409940	4048489
Propellant Utilization Valve	251351-11	4068944
Main-Stage Control Valve	558069	8313568
Ignition Phase Control Valve	558069	8275775
Helium Control Valve	106012000	3793-0
Start Tank Vent and Relief Valve	557828-X2	4046446
Helium Tank Vent Valve	106012000	342277
Fuel Bleed Valve	309034	4077749
Oxidizer Bleed Valve	309029	4077746
Augmented Spark Igniter Oxidizer Valve	308880	4077205
P/A Purge Control Valve	557823	4073021
Start Tank Fill/Refill Valve	558000	4079001
Fuel Flowmeter	251225	4077752
Oxidizer Flowmeter	251216	4074114
Fuel Injector Temperature Transducer	NA5-27441	12401
Restartable Ignition Detect Probe	XEOR915389	211

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter, in.	Installation Date	Comments
Gas Generator Fuel	RD251-4107	0.480	8-18-67	---
Gas Generator Oxidizer	RD251-4106	0.281	8-18-67	---
Oxidizer Turbine Bypass Valve	RD273-8002	1.571	7-31-67	RFD*-AEDC 58-67
Main Oxidizer Valve Closing Control	410437	8.65	8-28-67	RFD-AEDC 17-1-67
Oxidizer Turbine Exhaust	RD251-9004	9.99	1-18-67	Size Verification
Augmented Spark Igniter Oxidizer	406361 None	0.137 0.125	8-10-67	RFD-AEDC 62-67

*RFD - Rocketdyne Field Directive

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1801-07 AND J4-1801-08)

Modification	Completion Date	Description of Modification
RFD*-67-67	9-11-67	Re-routed Primary Seal Drain Line per ECP† J2-620
RFD-64-1-67	9-11-67	Installed Primary Seal Drain Line Simulation Tubes

*RFD - Rocketdyne Field Directive
†ECP - Rocketdyne Engineering Change Proposal

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1801-07 AND J4-1801-08)

Replacement	Completion Date	Component Replaced
UCR*-007393	9-5-67	Gas Generator Outlet Temperature Transducer

*UCR-Unsatisfactory Condition Report

TABLE V
OXIDIZER PUMP PRIMARY SEAL DRAIN TUBES

Type	Tube Number	Description
Actual Drain	1	Oxidizer pump primary seal drain per modification ECP620 canted overboard and equipped with pressure measurement (POPSD-1) at the oxidizer pump, Fig. 8b.
Simulated Drains	5 and 6	Simulated seal drains with burnout tubes, supplied with gaseous oxygen on firing 08A, coin-type plug on burnout end, Fig. 8e. Oxygen flow metered by orifices with pressure and temperature measurements as shown in Fig. 8a.
Experimental Drain Tubes-Type I	2, 3, and 4	Burnout tubes, coin-type plug on burnout end, upper end sealed, equipped with pressure measurement (POPSD-2, -3, and -4 for tubes 2, 3, and 4, respectively) and fabricated with a blowout port soft soldered, as shown in Figs. 8a and d.
Type II	9 and 10	Same as Type I, except fabricated without blowout port with pressure measurements, POPSD-9 and POPSD-10, for tubes 9 and 10, respectively, as shown in Figs. 8c and h.
Type III	7 and 8	Same as Type II, except open to cell on upper end, tube 8 equipped with soft-soldered blowout port, and equipped with immersion and surface thermocouples, TOPSD-7, TSOPSD-7, TOPSD-8, and TSOPSD-8, for tubes 7 and 8 (immersion and surface), respectively, as shown in Figs. 8b, f, and g.
Type IV	11 and 12	Burnout tubes, open on burnout end, sealed at upper end and equipped with pressure measurement (POPSD-11 and POPSD-12 for tubes 11 and 12, respectively), as shown in Figs. 8c and i.
Type V	13 and 14	Drain tubes, canted overboard, upper end sealed on tube 13 and open to cell on tube 14 and equipped with pressure and immersion temperature measurement (POPSD-13 and TOPSD-13, respectively) on tube 13 and immersion and surface temperature measurements (TOPSD-14 and TSOPSD-14, respectively) on tube 14, as shown in Figs. 8c, j, and k.

TABLE VI
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

		Time, min: t - 80, t - 70, t - 60, t - 50, t - 40, t - 30, t - 20, t - 10, t - 0, t + 10
Turbopump and Gas Generator Purge (Purge Manifold System)	Helium; 82 - 125 psia 50 - 200°F (Nominal) 6 scfm at Customer Connect	10 min Propellant Drop 2-min Minimum Following Recirculation 1 to 3 min
Oxidizer Dome and Gas Generator LO_2 Injector (Engine Pneumatic System)	Helium; 400 ± 25 psig 50 - 200°F (Nominal) 230 scfm	15 min 1 sec (Supplied by Engine Helium Tank during Start and Cutoff Transients)
Oxidizer Dome (Facility Line to Port CO3A)	Nitrogen; 400 - 450 psig 100 - 200°F (Nominal) 200 scfm	45 min On at Engine Cutoff 10 min
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium; 400 ± 25 psig Ambient Temperature 2600 - 7000 scfm	15 min Main-Stage Operation (Supplied by Engine Helium Tank)
Thrust Chamber Jacket (Customer Connect) Panel	Helium; 40 - 60 psig 50 - 200°F (Nominal) 60 scfm	In Addition to 15 min
	Helium; 12 - 14 psig 50 - 200°F (Nominal) 10 scfm	On at Engine Cutoff 10 min
Thrust Chamber Temperature Conditioning	Helium; 1000 psig -300°F to Ambient 10 - 20 lb_m/min	15 min
Pump Inlet Pressure and Temperature Conditioning	Oxidizer; 35 to 48 psia -298 to -280°F Fuel; 28 to 46 psia -424 to -416°F	
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 to 1400 psia -300 to -140°F Helium; 1700 to 3250 psia -300 to -140°F	46 min
Crossover Duct Temperature Conditioning	Helium; -300°F to Ambient	1

[1]Conditioning temperature to be maintained for the last 30 min of pre-fire.

TABLE VII
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number, J -1801-		09A Target	09A Actual	06B Target	06B Actual	06C Target	06C Actual	06D Target	06D Actual
Time of Day, hr/Firing Date		11:10	9-12-67	11:29	9-12-67	13:40	9-12-67	14:00	9-12-67
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	92,500	100,000	101,000	100,000	103,000	100,000	106,300
Firing Duration, sec		30	30.073	5	3.066	30	30.071	6	5.066
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	28 ± 1	27.7	28 ± 1	27.6	48 ± 1	45.4	28.0 ± 1	27.4
	Temperature, °F	-421.4 ± 0.4	-421.5	-421.4 ± 0.4	-420.6	-421.1 ± 0.4	-421.0	-421.4 ± 0.4	-421.2
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	33 ± 1	36.2	48 ± 1	49.2	35 ± 1	34.9	46 ± 1	47.7
	Temperature, °F	-294.0 ± 0.4	-293.9	-295.3 ± 0.4	-295.0	-294.0 ± 0.4	-293.9	-293.3 ± 0.4	-294.6
Start Tank Conditions at Engine Start	Pressure, psia	1250 ± 10	1246	1200 ± 10	1193	1230 ± 10	1243	1400 ± 10	1393
	Temperature, °F	-140 ± 10	-141	-140 ± 10	-139	-140 ± 10	-143	-140 ± 10	-146
Helium Tank Conditions at Engine Start	Pressure, psia	---	2167	---	2313	---	2150	---	2331
	Temperature, °F	---	-143	---	-143	---	-147	---	-148
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat, TSC2-19	Ambient	-6	---	62	-60	-62	---	71
	Average	---	29	---	47	---	-82	---	43
Crossover Duct Temperature at Engine Start, °F	TFTD-2	-100 ± 13 [2]	-102	---	420	-100 ± 13 [1]	-111	---	444
	TFTD-3	-100 ± 15 [2]	-78	170^{+13}_{-0}	171	-100 ± 13 [2]	-103	170^{+13}_{-0}	174
	TFTD-6	-100 ± 15 [1]	-83	---	366	-100 ± 13 [1]	-99	---	386
Main Oxidizer Valve Closing Control Line Temperature at Engine Start, °F		---	43	---	40	---	23	---	34
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F		---	-138	---	-148	---	-161	---	-164
Pneumatic Control Package Temperature at Engine Start, °F		---	66	---	42	---	29	---	16
Fuel Lead Time, sec [1]		6	7.965	6	7.996	3	3.002	8	7.966
Propellant in Engine Time, min		60	90	---	---	60	60	---	---
Propellant Recirculation Time, min		10	12	10	11	10	10	10	14
Start Sequence		Normal	Normal	Normal	Normal	Auxiliary	Auxiliary	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-2A	---	40	---	-14	---	26	---	-19
Start Tank Discharge Valve Body Temperature at Engine Start, °F		---	4	---	-3	---	-17	---	-16
Vibration Safety Count Duration (msec) and Occurrence Time (sec) from t_0 [1]		--- / ---	2 / t_0 + 1.057	--- / ---	0 / ---	--- / ---	54 / t_0 + 1.023	--- / ---	0 / ---
Gas Generator Outlet Temperature, °F	Initial Peak	---	1050	---	2090	---	1330	---	2136
	Overshoot	---	---	---	---	---	---	---	---
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0) [1]		---	1.060	---	1.007	---	1.027	---	0.974
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) [1]		---	0.986	---	1.100	---	1.000	---	1.137
Main-Stage Pressure No. 2 (Ref. t_0) [1]		---	1.967	---	1.639	---	1.711	---	1.692
330-psia Chamber Pressure Attained, sec (Ref. t_0)		---	2.791	---	2.033	---	2.000	---	1.933
Propellant Utilization Valve Position at Engine Start, deg. Engine Start/t_0 + 10 sec		Open / Closed	Open / Closed	Open / ---	Open / ---	Null / Closed	Null / Closed	Open / ---	Open / ---

Notes: [1] Data were reduced from oscillogram.

[2] Component conditioning to be maintained within limits for last 13 min before engine start.

TABLE VIII
ENGINE VALVE TIMINGS

Firing Number J4-1801-	Start																					
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve Main Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
08A	0	0.148	0.139	0.447	0.092	0.256	-7.985	0.051	0.067	0.447	0.054	0.055	0.447	0.538	1.684	0.447	0.110	0.021	0.447	0.163	0.060	0.447	0.240	0.287
08B	0	0.148	0.135	0.446	0.093	0.258	-7.986	0.047	0.070	0.446	0.058	0.060	0.446	0.854	1.666	0.446	0.111	0.030	0.446	0.175	0.071	0.446	0.224	0.307
08C	0	0.148	0.140	0.448	0.096	0.265	-3.002	0.049	0.071	0.446	0.057	0.057	0.446	0.554	1.678	0.446	0.116	0.028	0.446	0.173	0.068	0.446	0.230	0.292
08D	0	0.160	0.144	0.447	0.093	0.259	-7.885	0.050	0.087	0.447	0.057	0.080	0.447	0.690	1.668	0.447	0.117	0.027	0.447	0.185	0.073	0.447	0.226	0.295
Pre-Fire Final Sequence	0	0.096	0.110	0.447	0.092	0.244	-1.010	0.040	0.071	0.447	0.050	0.043	0.447	0.563	1.540	0.447	0.088	0.027	0.447	0.132	0.051	0.447	0.208	0.290

Firing Number J4-1801-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
08A	30.073	0.122	0.329	30.073	0.080	0.193	30.073	0.072	0.018	30.073	0.027	0.014	30.073	0.257	0.572
08B	5.086	0.118	0.315	5.088	0.070	0.192	5.086	0.079	0.017	5.086	0.038	0.018	5.088	0.232	0.529
08C	30.071	0.121	0.320	30.071	0.086	0.200	30.071	0.075	0.013	30.071	0.030	0.014	30.071	0.265	0.527
08D	5.088	0.118	0.317	5.088	0.072	0.193	5.088	0.078	0.015	5.088	0.037	0.020	5.086	0.237	0.520
Pre-Fire Final Sequence	5.830	0.067	0.243	5.830	0.082	0.130	5.830	0.090	0.023	5.830	0.066	0.023	5.630	0.228	0.574

Notes: 1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data reduced from oscillogram.

TABLE IX
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1801-08A		Site	Normalized
Time, sec*		29.5	29.5
Overall Engine Performance	Thrust, lb_f	221,771	219,598
	Chamber Pressure, psia	749.5	739.3
	Mixture Ratio	5.647	5.637
	Fuel Weight Flow, lb_m/sec	79.32	78.36
	Oxidizer Weight Flow, lb_m/sec	447.90	441.69
	Total Weight Flow, lb_m/sec	527.23	520.05
Thrust Chamber Performance	Mixture Ratio	5.865	5.857
	Total Weight Flow, lb_m/sec	520.30	513.18
	Characteristic Velocity, ft/sec	7895.5	7896.3
Fuel Turbopump Performance	Pump Efficiency, percent	73.9	73.9
	Pump Speed, rpm	26,139	25,981
	Turbine Efficiency, percent	56.0	55.9
	Turbine Pressure Ratio	7.37	7.37
	Turbine Inlet Temperature, °F	1238	1220
	Turbine Weight Flow, lb_m/sec	6.92	6.87
Oxidizer Turbopump Performance	Pump Efficiency, percent	80.3	80.2
	Pump Speed, rpm	8471	8395
	Turbine Efficiency, percent	46.1	45.9
	Turbine Pressure Ratio	2.69	2.69
	Turbine Inlet Temperature, °F	788.0	775.5
	Turbine Weight Flow, lb_m/sec	6.01	5.96
Gas Generator Performance	Mixture Ratio	0.962	0.952
	Chamber Pressure, psia	645.1	638.0

TABLE IX (Concluded)

Firing Number J4-1801-08C		Site	Normalized
Time, sec*		29.5	29.5
Overall Engine Performance	Thrust, lb_f	223,203	221,591
	Chamber Pressure, psia	754.1	745.1
	Mixture Ratio	5.578	5.622
	Fuel Weight Flow, lb_m/sec	80.31	78.97
	Oxidizer Weight Flow, lb_m/sec	447.94	444.00
	Total Weight Flow, lb_m/sec	528.25	522.97
Thrust Chamber Performance	Mixture Ratio	5.789	5.839
	Total Weight Flow, lb_m/sec	521.30	516.08
	Characteristic Velocity, ft/sec	7929	7914
Fuel Turbopump Performance	Pump Efficiency, percent	73.6	73.6
	Pump Speed, rpm	26,296	26,101
	Turbine Efficiency, percent	56.6	56.4
	Turbine Pressure Ratio	7.37	7.37
	Turbine Inlet Temperature, °F	1254*	1243*
	Turbine Weight Flow, lb_m/sec	6.94	6.90
Oxidizer Turbopump Performance	Pump Efficiency, percent	80.3	80.3
	Pump Speed, rpm	8497	8423
	Turbine Efficiency, percent	46.2	45.9
	Turbine Pressure Ratio	2.69	2.69
	Turbine Inlet Temperature, °F	802.0	795.0
	Turbine Weight Flow, lb_m/sec	6.03	5.99
Gas Generator Performance	Mixture Ratio	0.972	0.965
	Chamber Pressure, psia	648.6	643.1

Site: Test Data

Normalized: Test Data Corrected to Standard Pump Inlet and Engine Ambient Pressure Conditions

*The data presented are for a 1-sec average of test measurements obtained from t_0 + 29 sec to t_0 + 30 sec.

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC test J4-1801-08 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFJT	Fuel Injector Temperature		On/Off	x		x		
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	x		x		
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Cloaed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tsnk Discharge Control Solenoid		On/Off	x	x	x		
	Sparka							
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No. 2		On/Off			x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flowa		gpm					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		
QF-2SD	Fuel Flow Stall Approach Monitor		0 to 9000	x		x		
QFRP	Fuel Recirculation		0 to 160	x				
QO-1A	Oxidizer	POF	0 to 3000	x		x		
QO-2	Oxidizer	POFA	0 to 3000	x	x	x		
QORP	Oxidizer Recirculation		0 to 50	x			x	
	Forcea		lb_f					
FSP-1	Side Load (Pitch)		±20, 000	x		x		
FSY-1	Side Load (Yaw)		±20, 000	x		x		
	Heat Flux		watts					
RTCEP	Radiation Thrust Chamber Exhauat Plume		Sr. cm^2 0 to 7	x				
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gaa Generator Vslve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Vslve		0 to 100	x		x		
	Preaaure		paia					
PA1	Test Cell		0 to 0. 5	x		x		
PA2	Test Cell		0 to 1. 0	x	x			
PA3	Test Cell		0 to 5. 0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x			x	
PC-3	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCASI-2	Augmented Spark Igniter Chamber	IG1	0 to 1000	x				
PCGG-1P	Gas Generator Chamber		0 to 1000	x	x	x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oacillo-graph	Strip Chart	X-Y Plotter
	Pressure							
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFASIJ	Augmented Spark Igniter Fuel Injection		0 to 1000	x				
PFJ-1A	Main Fuel Injection	CF2	0 to 1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0 to 1000	x	x			
PFJGG-1A	Gas Generator Fuel Injection	GF4	0 to 1000	x				
PFGG-2	Gas Generator Fuel Injection	GF4	0 to 1000	x		x		
PFMI	Fuel Jacket Inlet Manifold	CF1	0 to 2000	x				
PFOI-1A	Fuel Tapoff Orifice Outlet	HF2	0 to 1000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0 to 1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0 to 1500	x				
PFPD-2	Fuel Pump Discharge	PF2	0 to 1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0 to 100	x				x
PFPI-2	Fuel Pump Inlet		0 to 200	x				x
PFPI-3	Fuel Pump Inlet		0 to 200		x	x		
PFPS-1P	Fuel Pump Interstage	PF6	0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFUT	Fuel Tank Ullage		0 to 100	x				
PFVI	Fuel Tank Repressurization Line Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Repressurization Line Nozzle Throat		0 to 1000	x				
PGBNI	Bypaas Nozzle Inlet	TG8	0 to 200	x				
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHEOP	Oxidizer Recirculation Pump Purge		0 to 150	x				
PHES	Helium Supply		0 to 5000	x				
PHET-1P	Helium Tank	NN1	0 to 3500	x		x		
PHET-2	Helium Tank	NN1	0 to 3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0 to 750	x	x			
POBSC	Oxidizer Bootstrap Conditioning		0 to 50	x				
POBV	Gas Generator Oxidizer Bleed Valve	GO2	0 to 2000	x				
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x				
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		
POJGG-1A	Gaa Generator Oxidizer Injection	GO5	0 to 1000	x		x		
POJGG-2	Gaa Generator Oxidizer Injection	GO5	0 to 1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x				
POPSD-1	Oxidizer Pump Seal Drain Simulator		0 to 50	x				
POPSD-2	Oxidizer Pump Seal Drain Simulator		0 to 50	x				
POPSD-3	Oxidizer Pump Seal Drain Simulator		0 to 50	x				
POPSD-4	Oxidizer Pump Seal Drain Simulator		0 to 50	x				
POPSD-5D	Oxidizer Pump Seal Drain Simulator		0 to 50	x				
POPSD-5U	Oxidizer Pump Seal Drain Simulator		0 to 50	x				
POPSD-6D	Oxidizer Pump Seal Drain Simulator		0 to 50	x				
POPSD-6U	Oxidizer Pump Seal Drain Simulator		0 to 50	x				
POPSD-9	Oxidizer Pump Seal Drain Simulator		0 to 50	x				
POPSD-10	Oxidizer Pump Seal Drain Simulator		0 to 50	x				
POPSD-11	Oxidizer Pump Seal Drain Simulator		0 to 50	x				
POPSD-12	Oxidizer Pump Seal Drain Simulator		0 to 50	x				
POPSD-13	Oxidizer Pump Seal Drain Simulator		0 to 50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0 to 115	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 100	x				

TABLE III-1 (Continued)

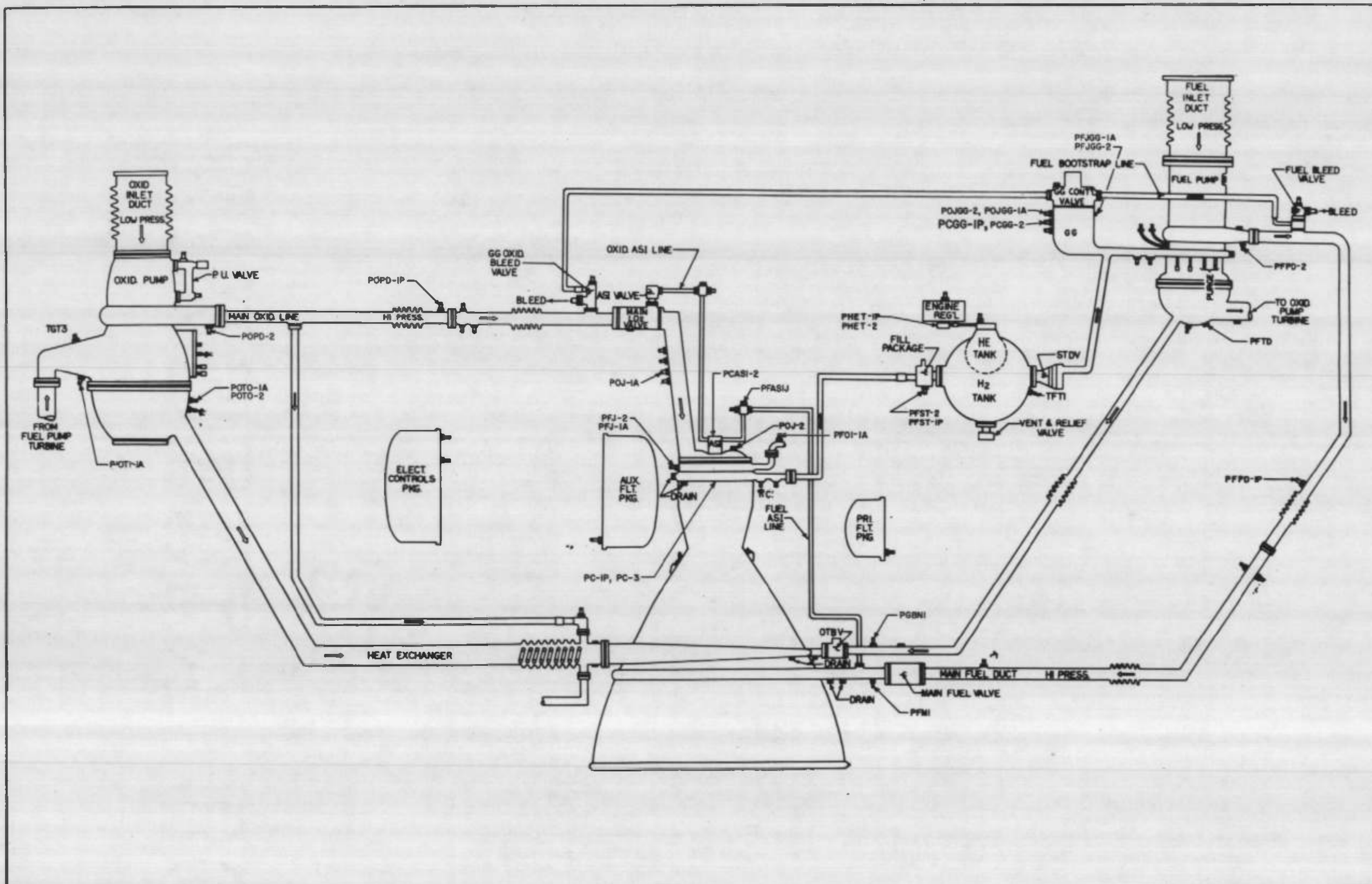
AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure							
POT1-1A	Oxidizer Turbine Inlet	TG3	0 to 200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0 to 100	x				
POUT	Oxidizer Tank Ullage		0 to 100	x				
POVCC	Main Oxidizer Valve Closing Control		0 to 500	x	x			
POVI	Oxidizer Tank Repressurization Line Nozzle Inlet		0 to 1000	x				
POVL	Oxidizer Tank Repressurization Line Nozzle Throat		0 to 1000	x				
PPUV1-1A	Propellant Utilization Valve Inlet	PO8	0 to 1000	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTCP	Thrust Chamber Purge		0 to 15	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		rpm					
NFP-1P	Fuel Pump	PFV	0 to 30, 000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15, 000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12, 000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15, 000	x				
	Temperatures		°F					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBHR-1	Helium Regulator Body (North Side)		-100 to +50	x				
TBHR-2	Helium Regulator Body (South Side)		-100 to +50	x			x	
TBPM	Bypass Manifold		-325 to +200	x				
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TCLC	Main Oxidizer Valve Closing Control Line Conditioning		-325 to +200	x				
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	
TFASIJ	Augmented Spark Igniter Fuel Injection	1FT1	-425 to +100	x		x		
TFASIL-1	Augmented Spark Igniter Line		-300 to +200	x			x	
TFASIL-2	Augmented Spark Igniter Line		-300 to +300	x			x	
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFD-1	Fire Detection		0 to 1000	x			x	
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x	x	x		
TFPB-1A	Fuel Pump Bearing		-425 to -325	x				
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPDD	Fuel Pump Discharge Duct		-320 to +300	x				
TFP1-1	Fuel Pump Inlet		-425 to -400	x				x
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-2	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFT1	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x				x
TFTD-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-1R	Fuel Turbine Discharge Collector		-200 to +900	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures							
TFTD-3R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-4R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-5	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to +1400	x			x	
TFTI-1P	Fuel Turbine Inlet	TFT1	0 to 1800	x			x	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x	x	x		
THET-1P	Helium Tank	NNT1	-350 to +100	x				x
TMOVC	Main Oxidizer Valve Actuator Conditioning		-325 to +200	x				
TNODP	Oxidizer Dome Purge		0 to -300	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2A	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-3	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-4	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-5	Oxidizer Bootstrap Line		-300 to +250	x				
TOBSC1	Oxidizer Bootstrap Conditioning Inlet		0 to 100	x				
TOBSCO	Oxidizer Bootstrap Conditioning Outlet		0 to 100	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPDS	Oxidizer Pump Discharge Skin		-300 to -100	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOP1-2	Oxidizer Pump Inlet		-310 to -270	x				x
TOPSD-5D	Oxidizer Pump Seal Drain Simulator		0 to 500	x				
TOPSD-5U	Oxidizer Pump Seal Drain Simulator		0 to 500	x				
TOPSD-6D	Oxidizer Pump Seal Drain Simulator		0 to 500	x				
TOPSD-6U	Oxidizer Pump Seal Drain Simulator		0 to 500	x				
TOPSD-7	Oxidizer Pump Seal Drain Simulator		0 to 1000	x				
TOPSD-8	Oxidizer Pump Seal Drain Simulator		0 to 1000	x				
TOPSD-13	Oxidizer Pump Seal Drain Simulator		-300 to +500	x				
TOPSD-14	Oxidizer Pump Seal Drain Simulator		-300 to +500	x				
TOPSDV	Oxidizer Pump Seal Vent		-300 to +200	x				
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Repressurization Line Nozzle Throat		-300 to +100	x				
TPCC	Pre-Chill Controller		-425 to -300	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TPPC	Pneumatic Package Conditioning		-325 to +200	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-2	Thrust Chamber Skin		-300 to +500	x				
TSC2-3	Thrust Chamber Skin		-300 to +500	x				
TSC2-4	Thrust Chamber Skin		-300 to +500	x				
TSC2-5	Thrust Chamber Skin		-300 to +500	x				
TSC2-6	Thrust Chamber Skin		-300 to +500	x				
TSC2-7	Thrust Chamber Skin		-300 to +500	x				
TSC2-8	Thrust Chamber Skin		-300 to +500	x				
TSC2-9	Thrust Chamber Skin		-300 to +500	x				
TSC2-10	Thrust Chamber Skin		-300 to +500	x				
TSC2-11	Thrust Chamber Skin		-300 to +500	x				

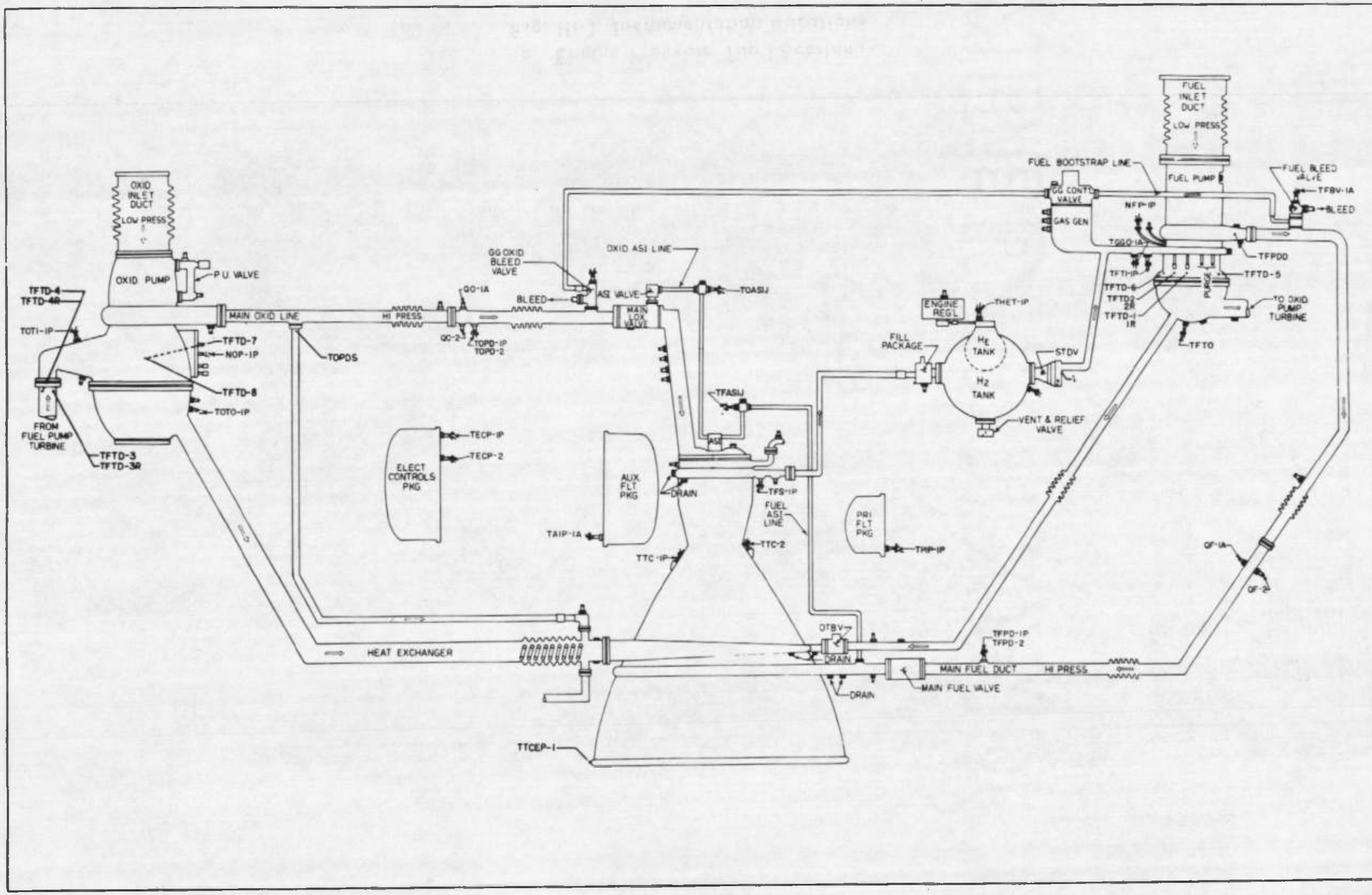
TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-14	Thrust Chamber Skin		-300 to +500	x				
TSC2-15	Thruat Chamber Skin		-300 to +500	x				
TSC2-16	Thrust Chamber Skin		-300 to +500	x				
TSC2-17	Thruat Chamber Skin		-300 to +500	x				
TSC2-18	Thrust Chamber Skin		-300 to +500	x				
TSC2-19	Thruat Chamber Skin		-300 to +500	x				
TSC2-20	Thruat Chamber Skin		-300 to +500	x				
TSC2-21	Thrust Chamber Skin		-300 to +500	x				
TSC2-22	Thrust Chamber Skin		-300 to +500	x				
TSC2-23	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSECP	Engine Control Package Skin		-50 to +250	x				
TSGGOC	Gas Generator Opening Control Port		-350 to +100	x				
TSOB	Oxidizer Bootatrap Shroud Skin		-200 to +100	x				
TSOPSD-7	Oxidizer Pump Seal Drain		0 to 1000	x				
TSOPSD-8	Oxidizer Pump Seal Drain		0 to 1000	x				
TSOPSD-14	Oxidizer Pump Seal Drain		-300 to +500	x				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				
TSOVAL-2	Oxidizer Valve Cloaing Control Line		-200 to +100	x			x	
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x				
TSOVC-2	Oxidizer Valve Actuator Filter Flange		-325 to +150	x				
TSPIP	Primary Instrument Package Skin		-50 to +250	x				
TSTC	Start Tank Conditioning		-350 to +150	x				
TSTDVCC	Start Tank Discharge Valve Closing Control Port		-350 to +100	x				
TSTDVOC	Start Tank Diacharge Valve Opening Control Port		-350 to +100	x				
TTC-1P	Thruat Chamber Jacket (Control)	CS1	-425 to +500	x				
TTCEP-1	Thrust Chamber Exit		-425 to +500	x				
TXOC	Croaaover Duct Conditioning		-325 to +200	x				
	Vibrations		g					
UFPR	Fuel Pump Radial 90 deg		±200		x			
UOPR	Oxidizer Pump Radial 90 deg		±200		x			
UTCD-1	Thruat Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3	Thrust Chamber Dome		±500		x	x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibration Safety Counts		On/Off			x		
	Voltage		volta					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 5	x				

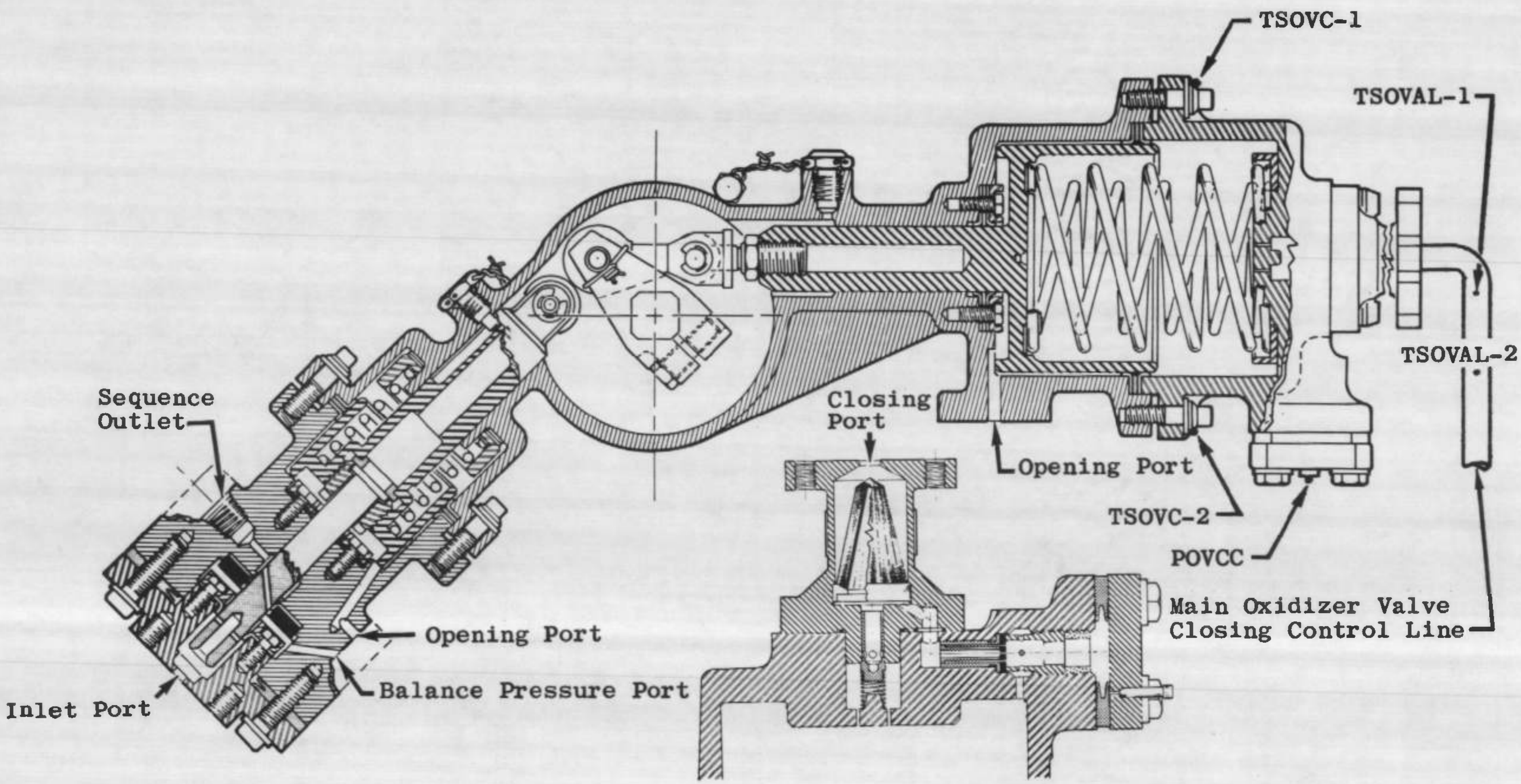


a. Engine Pressure Tap Locations

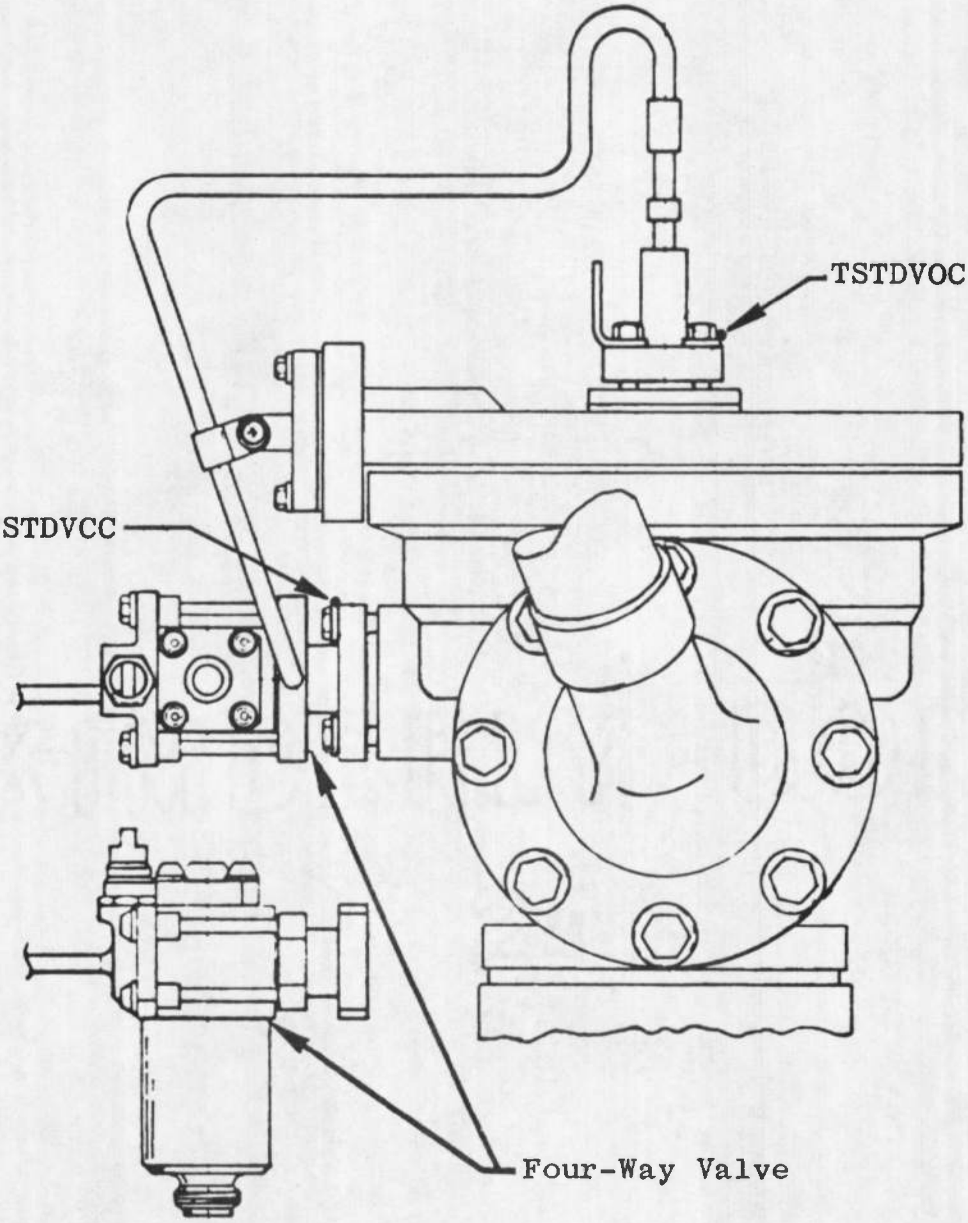
Fig. III-1 Instrumentation Locations



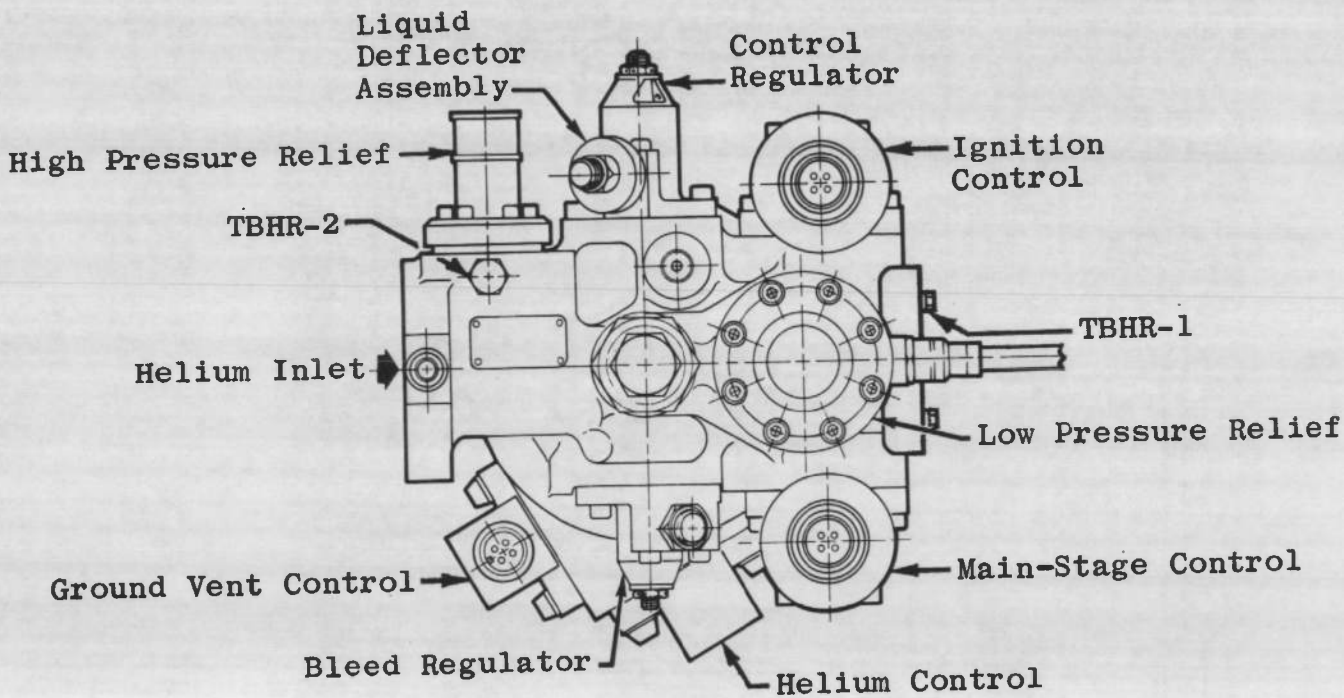
b. Engine Temperature, Flow, and Speed Instrumentation Locations
Fig. III-1 Continued



c. Main Oxidizer Valve
Fig. III-1 Continued

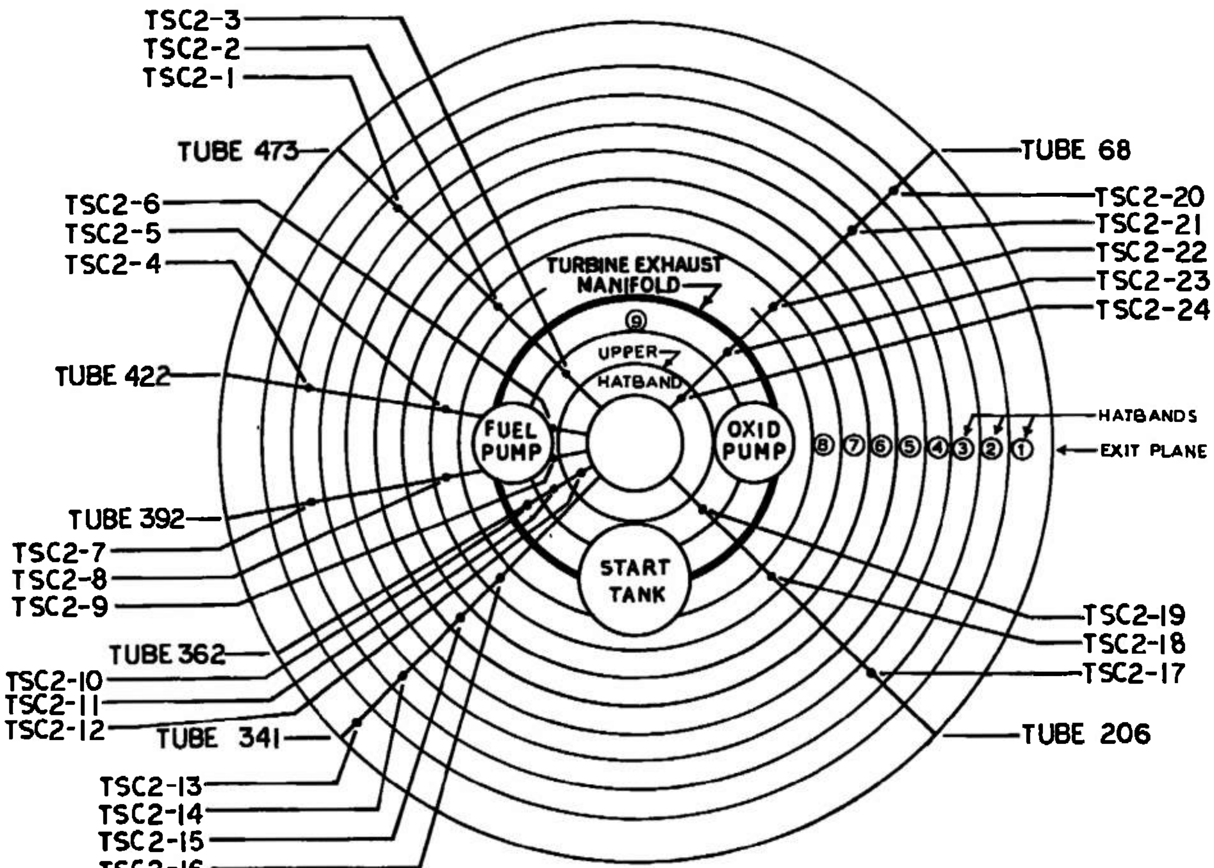


d. Start Tank Discharge Valve
Fig. III-1 Continued



Top View

e. Helium Regulator
Fig. III-1 Continued



VIEW LOOKING AFT

f. Thrust Chamber
Fig. III-1 Concluded

APPENDIX IV
METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

TABLE IV-1
PERFORMANCE PROGRAM DATA INPUTS

Item No.	Parameter
1	Thrust Chamber (Injector Face) Pressure, psia
2	Thrust Chamber Fuel and Oxidizer Injection Pressures, psia
3	Thrust Chamber Fuel Injection Temperature, °F
4	Fuel and Oxidizer Flowmeter Speeds, Hz
5	Fuel and Oxidizer Engine Inlet Pressures, psia
6	Fuel and Oxidizer Pump Discharge Pressures, psia
7	Fuel and Oxidizer Engine Inlet Temperatures, °F
8	Fuel and Oxidizer (Main Valves) Temperatures, °F
9	Propellant Utilization Valve Center Tap Voltage, volts
10	Propellant Utilization Valve Position, volts
11	Fuel and Oxidizer Pump Speeds, rpm
12	Gas Generator Chamber Pressure, psia
13	Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F
14	Fuel* and Oxidizer Turbine Inlet Pressure, psia
15	Oxidizer Turbine Discharge Pressure, psia
16	Fuel and Oxidizer Turbine Inlet Temperature, °F
17	Oxidizer Turbine Discharge Temperature, °F

*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower, hp
C*	Characteristic velocity, ft/sec
C_p	Specific heat at constant pressure, Btu/lb/°F
D	Diameter, in.
H	Head, ft
h	Enthalpy, Btu/lb_m
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
R	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Pressure drop, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiency
θ	Degrees
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

BIR	Bypass nozzle inlet (Rankine)
BNI	Bypass nozzle inlet (total)
C	Thrust chamber
CF	Thrust chamber, fuel
CO	Thrust chamber, oxidizer
CV	Thrust chamber, vacuum
E	Engine
EF	Engine fuel
EM	Engine measured
EO	Engine oxidizer
EV	Engine, vacuum
e	Exit
em	Exit measured
F	Thrust
FIT	Fuel turbine inlet
FM	Fuel measured
FY	Thrust, vacuum
f	Fuel
G	Gas generator
GF	Gas generator fuel
GO	Gas generator oxidizer
H1	Hot gas duct No. 1
H1R	Hot gas duct No. 1 (Rankine)
H2R	Hot gas duct No. 2 (Rankine)
IF	Inlet fuel
IO	Inlet oxidizer
ITF	Isentropic turbine fuel
ITO	Isentropic turbine oxidizer
N	Nozzle
NB	Bypass nozzle (throat)

NV	Nozzle, vacuum
O	Oxidizer
OC	Oxidizer pump calculated
OF	Outlet fuel pump
OFIS	Outlet fuel pump isentropic
OM	Oxidizer measured
OO	Oxidizer outlet
PF	Pump fuel
PO	Pump oxidizer
PUVO	Propellant utilization valve oxidizer
RNC	Ratio bypass nozzle, critical
SC	Specific, thrust chamber
SCV	Specific thrust chamber, vacuum
SE	Specific, engine
SEV	Specific, engine vacuum
T	Total
T_o	Turbine oxidizer
TEF	Turbine exit fuel
TEFS	Turbine exit fuel (static)
TF	Fuel turbine
TIF	Turbine inlet fuel (total)
TIFM	Turbine inlet, fuel, measured
TIFS	Turbine inlet fuel isentropic
TIO	Turbine inlet oxidizer
t	Throat
V	Vacuum
v	Valve
XF	Fuel tank repressurant
XO	Oxidizer tank repressurant

PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

$$W_E = W_{EO} + W_{EF}$$

Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

$$W_{XO} = 0.8 \text{ lb/sec}$$

$$W_{XF} = 1.8 \text{ lb/sec}$$

$$W_{GO} = W_T - W_{GF}$$

$$W_{GF} = \frac{W_T}{1 + r_G}$$

$$W_T = \frac{P_{TIF}\, A_{TIF}\, K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

$$W_C = W_{CO} + W_{CF}$$

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7\, P_c\, A_t}{W_C}$$

$$K_7 = 32.174$$

DEVELOPED PUMP HEAD

Flows are normalized by using the following inlet pressures, temperatures, and densities.

$$P_{IO} = 39 \text{ psia}$$

$$P_{IF} = 30 \text{ psia}$$

$$\rho_{IO} = 70.79 \text{ lb/ft}^3$$

$$\rho_{IF} = 4.40 \text{ lb/ft}^3$$

$$T_{IO} = -295.212\,°F$$

$$T_{IF} = -422.547\,°F$$

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}}\right)$$

$$K_4 = 144$$

$$\rho = \text{National Bureau of Standards Values f (P,T)}$$

Fuel

$$H_f = 778.16\,\Delta h_{OFIS}$$

$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$

$$h_{OFIS} = f(P,T)$$

$$h_{IF} = f(P,T)$$

PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_f = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$

$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC}\, Y_O$$

$$\eta_{OC} = K_{40} \left(\frac{Q_{PO}}{N_O}\right)^2 + K_{50} \left(\frac{Q_{PO}}{N_O}\right) + K_{60}$$

$$K_{40} = 5.0526$$

$$K_{50} = 3.8611$$

$$K_{60} = 0.0733$$

$$Y_O = 1.000$$

TURBINES

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO}\ H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO}\ \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B\ (P_{OO})$$

$$A = -1597$$

$$B = 2.3828$$

$$\text{IF } P_{OO} \geq 1010 \text{ Set } P_{OO} = 1010$$

$$\ln R = A_3 + B_3\ (\theta_{PUVO}) + C\ (\theta_{PUVO})^3 + D_3\ (e)^{\frac{\theta_{PUVO}}{7}} + E_3\ (\theta_{PUVO})\ (e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[(e)^{\frac{\theta_{PUVO}}{7}}\right]^2$$

$$A_3 = 5.5659 \times 10^{-1}$$

$$B_3 = 1.4997 \times 10^{-2}$$

$$C_3 = 7.9413 \times 10^{-6}$$

$$D_3 = 1.2343$$

$$E_3 = -7.2554 \times 10^{-2}$$

$$F_3 = 5.0691 \times 10^{-2}$$

$$\theta_{PUVO} = 16.5239$$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10}\ \Delta h_f\ W_T$$

$$\Delta h_f = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF}\ H_f}{\eta_f}\right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO} + K_{56}$$

$$B_{PO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_{56} = -15$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \frac{W_{PF} H_f}{\eta_f}$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer Weight Flow

$$W_{TO} = W_T - W_B$$

$$W_B = \left[\frac{2K_7 \quad H2}{\gamma_{H2-1}} (P_{RNC})^{\frac{2}{\gamma_{H2}}}\right]^{1/2} \left[1 - (P_{RNC})^{\frac{\gamma_{H2-1}}{\gamma_{H2}}}\right] \frac{A_{NB} \; P_{BNI}}{(R_{H2} T_{BIR})^{1/2}}$$

$$P_{RNC} = f\,(\beta_{NB}, \gamma_{H2})$$

$$\beta_{NB} = \frac{D_{NB}}{D_B}$$

$$\gamma_{H2}, M_{H2} = f(T_{H2R}, R_G)$$

$$A_{NB} = K_{13} D_{NB}$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

$$P_{TEFS} = \text{Iteration of } P_{TEF}$$

$$P_{TEF} = P_{TEFS} \left[1 + K_8 \left(\frac{W_T}{P_{TEFS}}\right)^2 \frac{T_{H2R}}{D^4{}_{TEF} \, M_{H2}} \left(\frac{\gamma_{H2-1}}{\gamma_{H2}}\right)\right]^{\frac{\gamma_{H2}}{\gamma_{H2-1}}}$$

$$K_8 = 38.8983$$

GAS GENERATOR

Mixture Ratio

$$r_G = D_1 (T_{H1})^3 + C_1 (T_{H1})^2 + B_1 (T_{H1}) + A_1$$

$A_1 = 0.2575$

$B_1 = 5.586 \times 10^{-4}$

$C_1 = -5.332 \times 10^{-9}$

$D_1 = 1.1312 \times 10^{-11}$

$T_{H1} = T_{TIFM}$

Flows

$$TC^*_{TIF} = D_2 (T_{H1})^3 + C_2 (T_{H1})^2 + B_2 (T_{H1}) + A_2$$

$A_2 = 4.4226 \times 10^3$

$B_2 = 3.2267$

$C_2 = -1.3790 \times 10^{-3}$

$D_2 = 2.6212 \times 10^{-7}$

$$P_{TIF} = P_{TIFS} \left[1 + K_8 \left(\frac{W_T}{P_{TIFS}} \right)^2 \frac{T_{H1R}}{D^4_{TIF} M_{H1}} \frac{\gamma_{H1} - 1}{\gamma_{H1}} \right]^{\frac{\gamma_{H1}}{\gamma_{H1} - 1}}$$

$K_8 = 38.8983$

Note: P_{TIF} is determined by iteration.

$T_{HIR} = T_{TIF}$

$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f\ (T_{HIR}, r_G)$

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13. ABSTRACT

Four firings of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. The firings were accomplished during test period J4-1801-08 at pressure altitudes ranging from 92,500 to 107,000 ft at engine start. The objectives of the test were to evaluate S-IVB/S-V start condition effects on (1) engine start transients, (2) gas generator outlet temperature, (3) augmented spark igniter operation, and (4) fuel pump high level stall margin for J-2 engine S/N J-2052. The accumulated firing duration was 70.32 sec. Satisfactory engine operation was obtained.

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gas generator ignition characteristics						
performance						

1 Rocket motors -- J-2
2 " " -- Performance
3 " " -- Ignition

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